DRAG ON NON-SPHERICAL SOLID PARTICLES IN POWER LAW FLUIDS

A thesis submitted

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MASTER OF TECHNOLOGY

By

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CERTIFICATE

This is to certify that the present work entitled "DRAG ON NON-SPHERICAL SOLID PARTICLES IN POWER LAW FLUIDS" has been carried out by Ms.Rajitha under my supervision and that this has not been submitted elsewhere for a degree.

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ABSTRACT

The effect of shape and orientation on the free settling behavior of cylinders in Newtonian and non- Newtonian fluids has been investigated experimentally. Several cylinders encompassing wide ranges of aspect ratio, 0.5-13.77, have been used in this work. Unbounded terminal velocity was measured as a function of the physical properties of a series of test fluids.

Conducting a few experiments on spheres settling in Newtonian media checked the reliability of the experimental observations. The raw experimental data on terminal velocity is converted to more useful dimensionless variables (Re, C_D and K).

Based on the large body of data for Newtonian as well as non-Newtonian fluids, it is demonstrated that the use of the equivalent volume sphere diameter gives an adequate method of characterizing the free settling behavior of non-spherical particles. Based on this notion, appropriate unified correlations have been developed for drag coefficient. The ratio of fall velocity of a falling cylinder to that of a spherical particle (having same volume as that of the non-spherical particle) is presented as a function of the shape factors of the cylinder. Also, the present results have been contrasted with the prior pertinent experimental and theoretical studies available in the literature. The present investigation encompasses the following ranges of conditions,

Newtonian Fluids

$10^{-6} \le \mathrm{Re} \le 143$; $0.154\mathrm{Pa.s} \le \mu \le 10.7\mathrm{Pa.s}$

non-Newtonian Fluids

$10^{-6} \le \mathrm{Re} \le 267$; $0.132\mathrm{Pa.s^n} \le k \le 8.07\mathrm{Pa.s^n}$ and; $0.46 \le n \le 0.83$

Chapter 1

INTRODUCTION

Fluid-particle systems are encountered in an overwhelming number of situations in chemical, mineral and processing industries; some examples of such applications are fluidized bed reactors, clarification processes, hydraulic transportation of coarse particles, mixing process of polymers and waste disposals of radioactive slurries etc. Reliable knowledge about the terminal settling velocities is required to design and to operate such systems successfully. For example, it is needed to predict the terminal velocities of particles in a fluidized bed system to minimize elutriation, to minimize blockage and for smooth functioning of hydraulic transportation systems, to calculate the power required to mix polymers it is needed to know the resistance offered by them, etc. Since, settling of single particles provides an idealization of many industrially important fluid-particle systems, extensive work has been done in the last century, mainly concentrating on the settling phenomenon of spheres in both Newtonian and non-Newtonian media. Therefore, the literature abounds with numerical solutions of the field equations describing the steady motion of a sphere, and empirical correlations of experimental data on the steady sedimentation of spheres in quiescent media. Suffice it to add here that based on a combination of numerical and experimental results, it is now possible to estimate the drag force or the terminal settling velocity of a spherical particle under most conditions of practical interest.

Though it is readily recognised that a very few engineering processes involve perfectly spherical particles, considerably much less work has been directed to understand the settling behavior of non-spherical but regular particles. This work has been carried out to study the settling behavior of cylinders (in the both orientations) in both Newtonian and non-Newtonian media. The settling of cylinders is encountered in some of the fluidized bed and packed bed catalytic reactions like desulphurization systems (where copper based sorbents are used in the form of cylindrical pellets), in the manufacturing of short fiber composites, in the hydraulic transport of fibrous materials. In all these applications, the variable of central interest is the free fall velocity and the resistance offered by these

particles, both of which are strongly dependent on the shape and the orientation. No concerted attempt has been made in the previous investigations to present a unified correlation for the cylinders settling in both horizontal and vertical orientations. Much less attention has been paid in studying the settling characteristics of cylinders in non-Newtonian fluid media. This work has been carried out to bridge this gap in the currently available body of information on this subject. However, the results reported herein pertain to purely shearthinning behavior of fluids.

In particular this work aims to present the drag coefficient of cylindrical particles settling in unbounded Newtonian and non-Newtonian media. On the basis of the present experimental results and those available in the literature, empirical correlations are presented for the drag coefficient of the cylindrical particles, settling in both the orientations in both Newtonian and non-Newtonian media. Furthermore, suitable expressions to estimate the ratio of the terminal settling velocity of a non-spherical to that of an equivalent spherical particle under identical conditions are also reported.

Chapter 2

LITERATURE REVIEW

In this chapter, a brief discussion of the prior studies on the free settling of regular but non-spherical shaped particles like cylinders, rectangular prisms, needles and cones including spheres in confined and in unconfined Newtonian and non-Newtonian media is presented which in turn, facilitates the setting out the objectives of the present work.

2.1 Newtonian Media

2.1.1 Drag On Spherical Particles

Considerable amount of work is available on all aspects of sphere motion in incompressible Newtonian media and consequently, a wealth of information is now available on the macroscopic as well as microscopic fluid flow phenomena in this flow configuration. Though it is readily recognised that very few engineering processes require perfectly spherical particles, the bulk of the research effort has been directed at spherical particles due to the obvious distinct advantages both in numerical and experimental studies. Most of the developments in this area are summarized in the classic book of Clift et al. (1978). Other sources of information include Happel and Brenner (1965) and Hetsroni (1982).

Several numerical methods are employed to calculate the drag coefficient for flow around a sphere. A semi-analytical solution is proposed by Kendoush (2000) for drag around a solid sphere in the intermediate range of Reynolds number ($10 \le Re \le 400$). Liao (2002) provided analytical solution for drag around a sphere in viscous medium. His predictions agree well with the experimental results in the region of Reynolds number, Re <30.

2.1.2 Drag On Non-Spherical Particles

Analogous studies involving non-spherical particles have been less extensive and the resulting literature is also not as cohesive as that in the case of spherical particles. The scant literature available on this topic has been summarized by Clift et al. (1978), Kim and Karrila (1991) and more recently by Chhabra et al. (1999). But a terse account of the

pertinent studies is included here, however. Theoretical solutions are available for predicting drag coefficients for flow over infinitely long cylinders and flat plates, oblates and spheroids in the range of Reynolds numbers from 0.01 to 10. Analytical expressions for the relevant stream function and drag coefficient are available in the literature. However, no analogous analysis for more practical shapes such as finite sized cylinders, rectangular prisms, cones etc. is available, except a few for the case of cylinders. Details of some of these studies are explained in the following discussion.

The drag force experienced by an object settling in a quiescent medium is strongly influenced by the shape and orientation of the body apart from the usual variables such as its size, rheological properties of settling medium and the relative density of the particle to that of the settling medium. For instance, the particle may settle with its axis normal or parallel to the direction of fluid motion, depending on the value of Reynolds number and the aspect ratio of the particle. A satisfactory mathematical description of particle shape is not yet available and it is one of the impediments in developing universal "drag curves", akin to the standard drag curve for sphere motion in Newtonian media. Currently there are two approaches available to represent and correlate the terminal settling data for non-spherical particles. In the first approach the usual drag coefficient-Reynolds number form is used. The works of Finn (1953), Jones and Knudsen (1961), List and Schemenaur (1971), Kasper et al. (1985), Unnikrishnan and Chhabra (1991), Venumadhav and Chhabra (1994), Sharma (1991), Rami (2000), Borah (2004), etc. illustrate the applicability of this approach. Much confusion, however, exist regarding the choice of a suitable linear dimension. Some investigators have found the use of the equal volume sphere diameter (d_{eq}) to be satisfactory (Venumadhav 1993; Sharma 1991; Leith 1987). Some others have advocated the use of a shape factor together with an equivalent volume sphere diameter. Pettyjohn and Christiansen (1948), McNown and Malika (1950) and Swamee and Ojha (1991) are a few of them. Yet some others have employed an equivalent diameter based on the specific surface area and/or sphere diameter based on equal surface areas, etc. Kasper (1982) has written an interesting article on the relative merits and demerits of a variety of equivalent diameters and shape factors currently used in correlating the drag coefficient data. Irrespective of the choice of a suitable equivalent diameter (whether in conjunction with a shape factor or not), this approach endeavors to reconcile drag coefficient data for variously shaped particles into one curve, akin to

standard drag curve for spheres. Sometimes additional geometric factors such as aspect ratio in case of cylinders also appear in the final drag expression, e.g., Cho et al. (1996). Chhabra et al. (1999) evaluated most of the widely accepted correlations to find the drag coefficient of non-spherical particles and also compared them with the experimental data from 19 independent studies embracing wide range of particle shape and sphericity, ψ

In the other approach, the terminal velocity measurements are represented and correlated in terms of a settling velocity ratio. In essence, this approach denotes the behavior of a non-spherical particle in comparison with that of a sphere having same volume as that of the non-spherical particle and some other geometric ratios. This approach introduces a sphericity factor, ψ which is defined as the ratio of the surface area of a sphere (of same volume as that of the non-spherical particle) to that of the non-spherical particle. Another linear dimension, d_n is introduced which is defined as the diameter of a sphere having same projected area as that of the settling object in the direction normal to the flow. As the projected area changes with orientation, it is calculated for the particle settling in both the orientations. Finally one defines a factor, K, which is the ratio of the settling velocity of a non-spherical particle to that of a sphere of the same volume. This approach has been used, for instance, by Heiss and Coull (1952), Leith (1987), Unnikrishnan and Chhabra (1991), Pettyjohn and Christiansen (1948), Singh and Roychoudhury (1969) and Chhabra et al. (2000) and more recently by Borah (2004). Though, this approach has proved to be successful for correlating the experimental results for variously shaped particles in creeping flow regime, a universal correlation encompassing all shapes of interest under wide conditions is yet to emerge.

Finally, some numerical methods have been also employed to study the flow around non-spherical objects in Newtonian media. For instance, Munshi et al. (1999) studied the flow around a disc at moderate Reynolds numbers. Tripathi et al. (1994) numerically studied the flow over spheroidal objects around oblates and prolate spheroids, etc.

2.2 Non-Newtonian Media

2.2.1 Drag On Spherical Particles

Over the past few decades, a considerable amount of work has been carried out on the steady flow of generalized Newtonian fluids around a sphere. From the theoretical

standpoint, it is readily acknowledged that the pertinent field equations describing the steady, incompressible flow around a sphere are highly non-linear due to complex rheological behavior of the fluid, even when the non-linear inertial terms are neglected altogether in non-Newtonian fluid. This complexity alone preludes the possibility of rigorous analytical solutions, even for the simplest non-Newtonian viscosity model, namely the power law model. Analytical results are available using variational method, by Wasserman and Slattery (1964), Cho and Hartnett (1983), Kawase and Moo-Young (1988) for creeping flow of power-law fluid over an unconfined sphere. These approximate results have been complemented by numerical results of various authors for the flow around a sphere at low Reynolds numbers. Lockyer et al. (1980), Crochet et al. (1984), Dazhi and Tanner (1985) studied the flow around a sphere in power law fluid in the creeping flow regime. Bush and Phan-Thein (1984) and Zheng et al. (1991) solved the problem for Carreau model.

As reviewed by Owens and Phillips (2002), all the experimental studies related to flow of non-Newtonian fluids past a sphere are mainly concerned with the low Reynolds number range. Extensive literature relating to the behavior of sphere has been critically reviewed by Chhabra (1993).Graham and Jones (1994) carried out a numerical study for power law liquids (n ranging from 0.4 to 1) flowing past a sphere in a tube for Reynolds number (based on sphere radius) ranging from 0.2 to 100 for two blockage ratios 1/30 and 1/50 which approximates the unbounded flow around a sphere. Jones (1998) studied the motion of a sphere falling under gravity in a constant-viscosity elastic liquid.

2.2.2 Drag On Non-Spherical Particles

In contrast, the contemporary literature on the settling motion of non-spherical particles in non-Newtonian media is indeed very limited; most of it has been summarized by Chhabra (1993). One configuration which has received considerable attention is the cross flow of viscoelastic fluids over infinitely long cylinders but rarely expressions/computed results for drag have been reported. The streamline pattern has been the main subject of enquiry (Chhabra, 1993), while the scant literature on non-spherical objects is tersely reviewed here. Brookes and Whitmore (1968) measured the drag on cylinders, discs, ellipsoids and the prisms in Bingham plastic fluids. Tripathi and Chhabra (1995) studied the flow of shear thickening (dilatant) fluid around a spheroid at moderate Reynolds numbers. For the same range of Re, the flow around a spheroid is solved for

shearthinning fluid (power law model) by Tripathi et al. (1994). Benjamin et al. (2003) reported the detailed flow characteristics of Herschel-Bulkley visco-plastic fluids around a circular cylinder. Some additional results for discs have been presented by Pazwash and Robertson (1975). However owing to the unrealistic values of the yield stress used by these investigators, the reliability of their correlation is uncertain. The free settling motion of slender bodies (thin wires and rods) in power law media has been studied both theoretically as well as experimentally by Manero et al.(1987) and Chiba et al. (1986) and subsequently by Unnikrishnan and Chhabra (1991) , Venumadhav and Chhabra (1994), and Chhabra et al.(2000). Unnikrishnan (1990), Venumadhav (1994) have done experiments on settling of cylinders in vertical orientation only in Newtonian and non-Newtonian media. This configuration has also received some impetus from the potential of falling needle or cylinder viscometry.

Apart from these investigations, scant data on the parallel motion of cones and irregular shaped gravel particles in power law media have respectively been reported by Sharma and Chhabra (1991) and Subrahmanyam and Chhabra (1990). Rodrigue et al. (1994) studied the various experimental results for non-spherical particles such as cylinders, square bars, crushed rocks etc. in power law and Carreau viscosity model fluids and presented the drag coefficient as a function of Reynolds number and Deborah number.
Corresponding but meager data on marble chips and discs are also available in the literature by Reynolds and Jones (1989). It is somewhat surprising that in none of these studies, attempt has been made at developing unified correlations.

2.3 Objectives

In particular, this work sets out to glean experimental data on the free settling of cylinders in Newtonian and pseudoplastic (power law model) fluids. Based on the new as well as previously available data, new unified correlations for the drag coefficient and settling (falling normal and parallel to the direction of motion in both v fluids) are developed and tested against the independent data

Chapter 3

EXPERIMENTAL MATERIALS, PROCEDURE AND DATA ANALYSIS

In this chapter, a brief discussion is presented about the experimental materials used, the experimental protocols and data analysis procedures. In particular, detailed information is provided about the physical properties of the test particles, rheological properties of the test fluids and the analysis of experimental data.

3.1 Experimental Materials

3.1.1 Test Fluids

In order to cover wide ranges of kinematic conditions (Reynolds number) numerous Newtonian and non-Newtonian fluids were used for conducting experiments on the settling of cylindrical objects.

3.1.1.1 Newtonian Fluids

Glycerine (manufactured by Loba Chemie Pvt. Ltd., Mumbai), Silicon oil (manufactured by Loba Chemie Pvt. Ltd., Mumbai) and aqueous solutions of Glucose solution were used as the Newtonian fluids. In all, ten Newtonian solutions were used in this study. Tap water was used to prepare the glucose solutions of desired concentrations, under continuous stirring to get a homogeneous solution. The density of the bubble free solution was measured using a constant volume density bottle. Each measurement of density listed in Table 3.1 and Table 3.2 is an average of atleast two repeat measurements using fresh samples of test fluid. The viscosity of the test solutions was measured using the concentric cylinder geometry on Bohlin CV-100 viscometer, at the same temperature as that recorded during the experiment. A summary of the rheological properties of the Newtonian fluids used in this study are presented table 3.1. The viscosity is seen to vary by more than a factor of 70.

Table 3.1 Rheological properties of Newtonian Fluids used in the study

Fluid	Temperature, (K)	Density, (kg/m^3)	Viscosity, (Pa.s)
Glycerine	305	1263	0.267
Silicon oil	304	1047	0.323
Glucose solution (92.5%)	302	1590	10.7
Glucose solution (87.5%)	298	1375	1.28
Glucose solution (80%)	301	1270	0.652
Glucose solution (75%)	299	1230	0.54
Glucose solution (72.5%)	302	1160	0.4
Glucose solution (70%)	286	1130	0.32
Glucose solution (50%)	302	1050	0.204
Glucose solution (35%)	301	1000	0.154

3.1.1.2 Non-Newtonian Fluids

Non-Newtonian fluids of various degrees of shear thinning behavior were used .These were aqueous solutions of Carboxy Methyl Cellulose (manufactured by Loba Chemie, Mumbai), Methyl Cellulose (manufactured by Loba Chemie, Mumbai) and Sodium CMC (manufactured by Loba Chemie, Mumbai) of various concentrations. In all, thirteen non-Newtonian solutions were used to carry out the experiments in this study. All the solutions were prepared by adding the required amount of polymer in tap water under continuous stirring, to get a homogeneous solution. To avoid cluster formation, the polymer was added in small amounts during the entire period of mixing. To avoid degradation by bacterial attack 4-5 ppm of Formalin (s.d-fine chemie Pvt. Ltd., Mumbai) was added to the polymer solutions. The density of the each test fluid was measured using a constant density volume bottle. The concentric cylinder geometry in the Bohlin CV-100 rheometer was used to measure the shear stress-shear rate behavior at the temperature recorded during the experiments. All the solutions exhibited viscous shear-thinning behavior that can be well described by the usual two parameter power law model in the range of shear rate $0.01\text{-}200\,s^{-1}$. The shear stress-shear rate data are taken both before and after the settling experiments and found to be virtually indistinguishable from each other, thereby suggesting that no degradation had taken place during the course of experiments. The physical and rheological characteristics of the non-Newtonian fluids used in this study are summarized in table 3.2.

Table 3.2 Rheological Properties Of Non-Newtonian Fluids Used In The Study

Fluid	Temperature, (K)	Density, (kg/m^3)	n	k ($Pa.s^n$)
CMC Solution (2.5%)	301	1300	0.46	8.077
CMC Solution (1.5%)	301	1100	0.546	1.2184
CMC Solution (1.35%)	297	1000	0.634	0.628
CMC Solution (1.2%)	297	1000	0.654	0.4718
CMC Solution (1%)	297	1000	0.671	0.2753
CMC Solution (0.8%)	295.5	1000	0.66	0.135
Methocel Solution (1.2%)	295	1000	0.718	1.7128
Methocel Solution (1%)	294	1000	0.708	0.8928
Methocel Solution (0.8%)	291	1000	0.688	0.743
Methocel Solution (0.7%)	291	1000	0.697	0.4517
Sodium CMC Solution (1.2%)	287	1000	0.78	1.1722
Sodium CMC Solution (1%)	287	1000	0.796	0.3813
Sodium CMC Solution (0.8%)	287	1000	0.826	0.1323

3.1.2 Test Particles

Numerous circular cylinders and discs made of different materials were used in this study. In order to cover wide ranges of Reynolds number and sphericity, particles made of aluminium, glass, perspex, PVC and stainless steel were used. In all, seventy nine test cylinders encompassing the length to diameter ratio 0.5 to 13.77 were used in this study. The geometrical dimensions of the test particles were measured using a micro meter (reading up to 0.01mm) and vernier calipers (reading up to 0.02mm).The average mass of a particle in a particular material batch was determined from individual weighings, using a balance with resolution of 1mg, of approximately 15 non-spherical particles. From these measurements the mean density was estimated. Sphericity is calculated as the ratio of surface area of a sphere equal volume to the surface area of the non-spherical particle. Table 3.3 presents the physical and geometrical properties of the test particles.

Table 3.3 Geometrical And Physical Properties Of The Test Particles

Particle ID	Diameter, mm	Length, mm	d_{eq}, mm	Sphericity	Density, kg/m^3
A1	3.08	15.049	5.98	0.702	2811.7
A2	3.08	6.037	4.41	0.835	2811.7
A3	3.08	3.068	3.52	0.874	2811.7
A4	3.08	1.540	2.79	0.826	2811.7
A5	6.03	30.029	11.79	0.697	2811.7
A6	6.03	12.090	8.711	0.830	2811.7
A7	6.03	6.030	6.9	0.870	2811.7
A8	6.03	3.020	5.48	0.826	2811.7
A9	7.98	40.100	15.646	0.696	2811.7
A10	7.98	16.096	11.54	0.831	2811.7

A11	7.98	8.076	9.17	0.874	2811.7
A12	7.98	4.086	7.31	0.829	2811.7
A13	10.1	50.096	19.717	0.698	2811.7
A14	10.1	20.028	14.525	0.833	2811.7
A15	10.1	9.999	11.52	0.874	2811.7
A16	20.4	275.400	43.325	0.657	2830
A17	20.4	193.800	38.536	0.717	2830
A18	20.4	122.400	33.063	0.791	2830
A19	20.4	61.200	26.242	0.870	2830
S1	3.08	15.049	5.98	0.702	7832.5
S2	3.08	6.037	4.41	0.835	7832.5
S3	3.08	3.068	3.52	0.874	7832.5
S4	3.08	1.540	2.79	0.826	7832.5
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P1	3.08	15.049	5.98	0.702	1200
P2	3.08	6.037	4.41	0.835	1200
P3	3.08	3.068	3.52	0.874	1200
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P5	6.03	30.029	11.79	0.697	1200
P6	6.03	12.090	8.711	0.830	1200
P7	6.03	6.030	6.9	0.870	1200
P8	6.03	3.020	5.48	0.826	1200
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PC1	3.08	15.049	5.98	0.702	1535
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PC10	7.98	16.096	11.54	0.831	1535
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PC12	7.98	4.086	7.31	0.829	1535
PC13	10.1	50.096	19.717	0.698	1535
PC14	10.1	20.028	14.525	0.833	1535
PC15	10.1	9.999	11.52	0.874	1535
G1	5.5	25.040	10.435	0.713	2540
G2	5.5	21.170	9.87	0.740	2540
G3	5.5	17.790	9.311	0.767	2540
G4	5.5	14.750	8.75	0.794	2540
G5	5.5	12.450	8.3	0.818	2540
G6	5.5	9.450	7.54	0.848	2540
G7	5.5	6.408	6.62	0.872	2540
G8	5.5	4.000	5.66	0.863	2540
G9	7.84	24.382	13.096	0.774	2540
G10	7.84	19.992	12.26	0.8	2540
G11	7.84	16.229	11.435	0.83	2540
G12	7.84	11.650	10.24	0.86	2540
G13	7.84	10.200	9.79	0.87	2540
G14	7.84	8.193	9.1	0.873	2540
G15	7.84	6.131	8.26	0.87	2540

3.1.3 Fall Vessels

To obtain the settling velocity data of the particles in an unbounded medium, free from wall effects, two rectangular tanks made of transparent perspex sheets were used for conducting the experiments.

The dimensions of the small tank are $445 \times 205 \times 310 mm^3$. The height of the liquid column was approximately 280mm, this was divided into three sections, the first and last sections were of length 100mm each, to allow the test particle to reach to its terminal velocity and for the end effects to be negligible (Vroskaya and Taganov (1979)). The length of the observation column was about 80mm.

The dimensions of the big tank are $1140 \times 305 \times 305 mm^3$. The height of the liquid column was approximately 1000mm, containing two test sections of length 300mm each and separated from each other by 100mm. The first and last sections were of length 150mm each. This distance is believed to be sufficient for the particles to reach to its terminal velocity and for the end effects to be negligible (Peden and Luo (1987), Venumadhav (1993), Unnikrishnan (1990), Borah (2004)).

The diameter ratio was defined as the diameter of the largest particle used for the experiments to that of the tank (was estimated in both the orientations of the particle).
The diameter and length of the largest particle used for the experiments were 10.1mm and 275.4mm respectively. While conducting the experiments the particles having largest aspect ratio (A16, A17, A18) were dropped only in vertical orientation (when the axis of the particle is parallel to the direction of fluid flow), in order to avoid the wall effects on the settling phenomenon of these particles. The diameter ratio according to the definition was found to vary between 0.007 - 0.112, hence it is assumed that the effect of finite boundaries on the settling velocity of the particles is negligible, and the settling is assumed to be occurring in an unbounded medium

3.2 Experimental Procedure

The test fluids were filled in the tank 24 hours prior to the commencement of the experiments. This was done to allow the air bubbles to escape from the test fluid so as to provide a homogeneous settling medium, and to avoid any temperature difference

between the test fluid and the surroundings during the experiment, as this can affect the rheological properties of the fluid.

The particles were soaked in the test fluid well before the commencement of the drop tests, so that no air bubble was attached to the test particle when it was dropped in the fluid medium. The particles were introduced into the tank beneath the surface of the liquid medium with their axis parallel as well as perpendicular (orientation being changed manually) to that of the tank and as close to the center of the tank as possible. The time taken for each particle to pass through the test section was measured using a 'stop watch', reading upto 0.01 seconds. Only those results were accepted for which concordant fall times were obtained. Each velocity value represents an average of three repeat measurements thereby minimizing the experimental uncertainty. Apart from the quantitative time measurement the change in the orientation of the particle was visually recorded. It was observed that the change in orientation depended on the Reynolds number, concentration of the fluid and the aspect ratio of the particle.

3.3 Analysis Of The Experimental Data

Since the ratio of the diameter of the largest test particle to that of the tank is considerably small, the particle is assumed to be settling in an unbounded medium. The terminal velocities (V_t) were calculated from the known fall times for each particle. Two different approaches were used to analyze the settling data. In the first approach the drag coefficient (C_D) is correlated with the Reynolds number (Re).The Drag force is the force exerted by the fluid on the solid, generated due to the relative motion between the solid and the fluid, acting in the direction of flow. At steady state the drag force on the particle is balanced by its buoyant weight.

$$F_D = g.\Delta\rho\left(\pi/6\right)d_{eq}^{3}. \tag{3.1}$$

The drag coefficient C_D, is defined as shown below,

$$C_D = \frac{F_D}{\left(\left(\frac{\pi d_{eq}^{2}}{4}\right)\left(\frac{1}{2}\rho_f V_t^{2}\right)\right)} \tag{3.2}$$

An expression for drag coefficient is obtained using the steady state force balance on the settling object.

$$C_D = \frac{4}{3}\frac{gd_{eq}}{V_t^2}\left(\frac{\rho_p - \rho_f}{\rho_f}\right) \tag{3.3}$$

d_{eq} is the equivalent volume sphere diameter, defined as the diameter of a sphere having the same volume as that of the non-spherical test particle.

Thus for instance, for a cylinder of length l and diameter d , it can be shown,

$$d_{eq} = \left(1.5d^2 l\right)^{1/3} \tag{3.4}$$

From the known physical properties of the experimental materials and the calculated terminal velocities of the test particles Reynolds number is calculated as follows. The dimensional analysis suggests the following definition for the Reynolds number,

for power law fluids, $$Re = \frac{d_{eq}^{\ n} V_t^{\ 2-n} \rho_f}{k} \tag{3.5}$$

which for n = 1 reduces to its expected definition for Newtonian fluids.

In the first instance, an equivalent volume sphere diameter is believed to be sufficient to account for the shape of the particle. The drag coefficient is expected to be a function of the Reynolds number and the aspect ratio of the particle,

$$C_D = f\left(Re, l/d\right) \tag{3.6}$$

In the case of Non-Newtonian fluids the drag coefficient may also show an additional dependence on the power law index, 'n' .i.e.,

$$C_D = f\left(Re, l/d, n\right) \tag{3.7}$$

This method of correlating data for cylinders and the other regular shaped particles has been successfully employed for Newtonian fluids by Finn (1953), Jones and Knudsen (1961), List and Schemenaur (1971) and Kasper et al. (1985), and for non-Newtonian fluids by Unnikrishnan (1990), Sharma (1991), Venumadhav (1993) and Rami (2000) .

In the second approach of analyzing the terminal velocity data, a settling velocity ratio is correlated with the geometric ratios characterizing the shape of the non spherical particle in relation to a sphere. The settling velocity ratio, K is defined as the ratio of the settling velocity of a non spherical particle to that of a spherical particle of the same volume under identical settling conditions.

The terminal settling velocity of a spherical particle having equal volume as that of the non-spherical particle in both Newtonian and non-Newtonian media was estimated from the unpublished work of Renaud et al. (2004). They have reported a correlation for the

drag coefficient as a function of C_{D0}, d_{eq}, n, X, β, k', b, A_c, A_p and α. The relation between these variables is presented as,

$$C_D = C_{D0} + \frac{A_c}{A_p} C_{D\infty} C_{D0}^{2\beta} k' \left[\frac{6Xb}{6Xb + C_{D0}}\right]^{\beta} + C_{D\infty}\left[\frac{6bX}{6bX + 128C_{D0}}\right]^{11/12} \quad (3.8a)$$

where,

$$C_{D0} = \frac{24X}{Re} \quad (3.8b)$$

$C_{D\infty}$ is the constant value of drag coefficient approached in the Newton's regime of settling.

$$C_{D\infty} = 0.44. \quad (3.8c)$$

A_c and A_p are, the total surface area and projected area (normal to the direction of settling) of the non-spherical particle.

For a cylinder, $A_c = \pi dl + \frac{\pi d^2}{2}$ (3.8d)

$$X = (0.992)6^{\frac{n-1}{2}}\left(\frac{3}{n^2+n+1}\right)^{n+1}, \quad (3.8e)$$

$$\alpha = \frac{2.985}{n^2+n+1} \quad (3.8f)$$

$$b = \exp^{3(\alpha - \ln 6)} \quad (3.8g)$$

$$\alpha_o = 3$$

$$k' = \frac{\alpha_0 - \alpha}{2\alpha_0\alpha}\exp\left[3\left(\frac{\alpha_0 - \alpha}{2\alpha_0\alpha}\right)\ln 3\right] \quad (3.8h)$$

$$\beta = \frac{11}{48}\sqrt{6}\left[1 - \exp\left\{\left(\frac{\alpha_0 - \alpha}{\alpha(\alpha_0 - 1)}\right)^2 \ln\frac{\sqrt{6}-1}{\sqrt{6}}\right\}\right] \quad (3.8i)$$

The terminal velocity of a spherical particle settling in a Newtonian fluid is found by substituting n = 1 in Equation (3.8).

It can be observed that X = 0.992 and $\alpha = 0.995$ in Newtonian media, i.e., for n=1.

The advantage of the settling velocity ratio approach is that, it enables the prediction of the settling velocity of a non spherical particle from that of an equal volume sphere. From

the literature it is observed that the settling velocity ratio correlates rather well with the following form of functional dependence.

$$K=f\left(\left(\frac{d_{eq}}{d_n}\right),\psi\right) \quad , \tag{3.9}$$

where d_n is the diameter of a sphere having the same projected area as that of the non spherical particle, which is obviously a function of the orientation of the particle.

For a cylinder settling in horizontal orientation, it is defined by,

$$d_n=\left(\frac{4dl}{\pi}\right)^{0.5} \tag{3.10a}$$

For a cylinder settling in vertical orientation, it reduces to the diameter of the cylinder, that is, $d_n=d$.

The sphericity ψ is defined as the ratio of surface area of a spherical particle to that of a non spherical particle, for the equal volumes of the two particles.

$$\psi=\frac{\left(1.5d^2l\right)^{2/3}}{\left(dl+\frac{d^2}{2}\right)} \quad . \tag{3.11}$$

This approach has been successfully used by Pettyjohn and Christiansen (1948), Heiss and Coull (1952), Singh and chowdhury (1969), Unnikrishnan (1990), Sharma (1991) and Venumadhav (1993).

In this study, all the raw experimental data have been converted into useful dimensionless groups as C_D, Re, ψ , d_{eq}/d_n etc. These in turn will be used to establish the functional dependences of drag on the pertinent system variables.

Chapter 4

RESULTS AND DISCUSSION

4.1 Rheological Properties Of Test Media

As expected, aqueous solutions of glucose and of Glycerine and Silicon oil displayed the Newtonian fluid behavior; the resulting values of the viscosity along with the other physical properties are presented in Table 3.1.

The representative shear stress-shear rate for some of the aqueous solutions of Carboxy Methyl Cellulose, Methyl Cellulose and Sodium CMC used in this study are shown in Figures 4.1 and 4.2. All non-Newtonian test fluids used in this study exhibited shear-thinning characteristics. Although, the test liquids were not checked for possible viscoelastic effects, but these were likely to be negligible due to relatively low molecular weight as well as low concentration of polymers used in this study.. An examination of the viscometric data shown in Figures 4.1 and 4.2 suggests that the usual two parameter power law model can be used to adequately represent the shear-thinning behavior of the non-Newtonian fluids.

$$\tau = k\left(\dot{\gamma}\right)^{n} \tag{4.1}$$

The resulting values of 'n' and 'k' estimated using non-linear regression along with the other physical properties of test fluids are listed in Tables 3.1 and 3.2.

4.2 Calibration Results

Limited experiments were carried out with spherical particles to establish the reliability of the experimental techniques and to gauge the overall accuracy of the results. Figure 4.3 shows the dependence of the drag coefficient on the Reynolds number for spheres along with the standard drag curve (Clift et al., 1978). A reasonable agreement is seen to exist with the average and maximum errors being 12.69% and 29.7% respectively.

Further verification of the experimental procedure has been done by comparing the present results with the velocity predictions using the correlation of Hartman et al. (1994)

for non-spherical particles. The main aim of their work was to develop correlations explicit in particle size. They also made use of the fact that the drag coefficient is a function of particle shape alone in Newton's range of settling. Based on the premise that the effects of Reynolds number and particle shape are simply additive,

$$\log \mathrm{Re}(Y,\psi) = \log \mathrm{Re}(Y,1) + P(Y,\psi) \tag{4.2a}$$

where, $$Y = \frac{C_D}{\mathrm{Re}} = \frac{\left(\frac{4}{3}\right) g(\rho_p - \rho_f)\mu}{\rho_f^2 V_t^3} \tag{4.2b}$$

The first term on the right hand side of Eq. 4.2a relates to the settling of a sphere where as the shape effects are completely contained in $P(Y,\psi)$ term. Based on the correlation of Turton and Levenspiel (1986), Hartman et al. (1994) reported the following equations for spheres explicit in Reynolds number;

$$\log \mathrm{Re}(Y,1) = 0.77481 - 0.56032 \log Y + 0.024246 \times (\log Y)^2 - 0.0038056 (\log Y)^3 \tag{4.2c}$$

and the function $P(Y,\psi)$ was found to be:

$$P(Y,\psi) = (1-\psi)\left\{-0.10118 \log Y + 0.092944 \times (\log Y)^2 - 0.0098356 (\log Y)^3 - 0.12666 (1-\psi) \log Y\right\} \tag{4.2d}$$

The above mentioned equations can be used in the range $10^{-2} \leq \mathrm{Re} \leq 16000$ and $0.67 \leq \psi \leq 1$.

At first, the Reynolds number is estimated from a knowledge of Y using Eq. 4.2c, from which the velocity is calculated using the known physical and rheological properties of the test fluid. The agreement between the experimental and the predicted values of the velocity by Hartman et al. (1994) seems to be good with the average and maximum deviations 22.8% and 72% respectively. Table 4.1 confirms the reliability of the present experimental results, where the experimentally recorded velocities are compared with the predictions made by Hartman et al. (1994). All the experimental data are compared with the predicted values available from prior studies and the maximum and average deviations are calculated. "Deviation" in the further discussion is defined as,

$$\text{deviation} = \frac{(\text{experimental value} - \text{predicted value})}{\text{experimental value}} \times 100 \tag{4.3}$$

4.2.1 Newtonian Media

4.2.1.1 Drag Results

In the first method of analyzing the settling velocity data, drag coefficient is correlated with the Reynolds number. From the knowledge of terminal settling velocities, drag coefficient, C_D is calculated as a function of Reynolds number for each individual fall test of the cylinders. Both C_D and Re are based on the equal volume sphere diameter, d_{eq}. Figure 4.4 shows the present experimental results for cylinders in both orientations in the form of Re and C_D plot on double logarithmic coordinates. As expected the slope of the drag curve gradually changed from −1 at low Re to higher values with the increase in Reynolds number. Owing to the wide ranging properties (density and viscosity) of the particle-fluid combinations, the Reynolds number varied from 10^{-6} to 143. The orientation is observed to be a significant variable apart from the physical and rheological properties of the experimental materials. More observations on the change in orientation of the settling objects are discussed in section 4.3.

Chhabra et al. (1999) evaluated the available methods for calculation of drag on non-spherical particles in incompressible viscous fluids at finite Reynolds numbers, by making comparisons between the predicted drag values and experimental data, and found the correlation by Ganser (1993), to give best predictive values based on the maximum and overall mean errors. The equation for drag on non-spherical particles, as suggested by Ganser (1993) is presented below.

$$\frac{C_D}{K_2}=\frac{24}{\mathrm{Re}}\left\{1+0.1118\left(\mathrm{Re}\,K_1K_2\right)^{0.6567}\right\}+\frac{0.4305}{1+\dfrac{3305}{\mathrm{Re}\,K_1K_2}} \tag{4.4a}$$

For isometric shapes, K_1 is defined as shown below,

$$K_1=\left[\left(\tfrac{1}{3}\right)+\left(\tfrac{2}{3}\right)\psi^{-0.5}\right]^{-1} \tag{4.4b}$$

For non-isometric shapes it is defined as,

$$K_1=\left[\left(\frac{d_n}{3d_{eq}}\right)+\left(\tfrac{2}{3}\right)\psi^{-0.5}\right]^{-1} \tag{4.4c}$$

and K_2 is defined as,

$$K_2 = 10^{1.8148(-\log\psi)^{-0.5743}} \quad (4.4d)$$

where, K_1 and K_2 account for the particle shape in the Stokes and Newton's regime of settling, respectively. The present experimental data is compared with the predictions of Equation 4.4a. Figure 4.4 presents the comparisons of the present experimental drag values with the predictions made by Ganser (1993). No discernable trends with respect to the particle shape or Reynolds number are observed. And the agreement between the two is satisfactory as the average and maximum deviations are 25.77% and 73.1% respectively.

The following equation for drag is developed by regression analysis from 555 data points, for cylinders settling in both the orientations.

$$C_D = \frac{31.78}{Re}\left(1+0.275Re^{0.531}\right), \quad 10^{-6} \le Re \le 143 \quad (4.5)$$

The comparison of the experimental drag values with the predictions of Equation 4.5 is presented in Figure 4.5.The agreement between the experimental drag coefficients and the predictions of Equation 4.5 is seen to be satisfactory and acceptable as the average and maximum deviations involved are 28.73% and 79.5% respectively.

4.2.1.2. Analysis Of Previous Works

This section includes the detailed analysis of the previous studies, which includes the investigations of Venumadhav (1993), Unnikrishnan (1990) and unpublished work of Sabiri (2004) on cylinders, of Borah (2004) and Sharma (1991) on cones and the numerical investigations on oblates and spheroids by Tripathi et al. (1994). The objectives of this section are, to check whether the present experimental values are consistent with the findings of the previous investigators mentioned above, and to evaluate the relative accuracy of the predictions made by various correlations available in the literature for drag on non-spherical particles settling in Newtonian media. The summary of the experimental data in Newtonian media, of the abovementioned investigators is presented in Table 4.1.

Venumadhav (1993) conducted experiments on settling of cylinders in various Newtonian and non-Newtonian fluids. His work limited to cylinders settling in vertical orientation in the range of Reynolds number mentioned below. The present experimental data combined with those of Venumadhav (1993), Unnikrishnan (1990) and Sabiri (2004) are compared with the correlation proposed by Venumadhav (1993), for cylinders falling in vertical orientation (axis of the cylinder being parallel to the flow direction).

$$C_D=\frac{24}{Re}\left(1+0.603Re^{0.529}\right),\quad 2\times10^{-4}\leq Re\leq 400 \tag{4.6}$$

Figure 4.6 presents the comparisons of the experimental drag coefficient including the prior studies on settling of cylinders in vertical orientation with the predictions made by Equation 4.6. The average percentage errors are presented in Table 4.2. From the Figure it can be concluded that the correlation proposed by Venumadhav (1993) is in good agreement with the experimental data.

The experimental drag values of the investigators mentioned above are compared with the predictions of Ganser (1993) in Figure 4.4. The solid lines in the figure represent the dependence of drag coefficient on sphericity apart from Reynolds number. It is observed from the figure that the effect of sphericity is negligible on the drag coefficient at low Reynolds numbers. In the figure solid line corresponding to s=0.4 represents the predictions of Equation 4.4a for particles having sphericity in the range of 0.3 to 0.5. Thus each solid line includes the predictions of drag coefficient for particles having sphericity in the range of ±0.1 of the sphericity mentioned in the figure. The agreement between the predictions of Ganser (1993) with the experimental drag values of all the investigators mentioned above is seen to be satisfactory. The deviations are presented in Table 4.2.

Chein (1994) re-analysed the data available in the petroleum engineering and processing literature and proposed the following expression for drag on non-spherical particles settling in Newtonian media.

$$C_D=(30/Re)+67.289\exp(-5.03\psi),\quad 0.2\leq\psi\leq1,\quad Re\leq5000 \tag{4.7}$$

Clearly, the drag coefficient is a function of both Reynolds number and sphericity as observed in Equation 4.7. Figure 4.7 presents the comparison between the present experimental values including the prior studies mentioned above with the predictions of drag coefficient estimated by Equation 4.7. Separate solid lines are used to indicate the predictions of drag using Equation 4.7 for particles having different sphericity. Each solid line includes the predictions of drag coefficient for particles having sphericity in the range of ± 0.1 of the sphericity mentioned in the figure. Thus the solid line indicating $s=0.4$ represents predictions of Equation 4.7 having sphericity in the range of 0.3 to 0.5. The agreement between the predictions of Chein (1994) and the experimental drag values is observed to be satisfactory, as seen from the figure. The deviations involved are presented in Table 4.2.

Renaud et al. (2004) proposed Equation 3.8a for drag on settling of non-spherical particles in Newtonian and non-Newtonian media. The present experimental values including some of the previously done work on cylinders and cones as mentioned above are compared with the predictions made by Equation 3.8. The predictions of drag coefficient in Newtonian media are found by substituting $n=1$ in Equation 3.8. The average and maximum deviations involved are summarized in Table 4.2. Figure 4.8 presents the comparisons between the present experimental drag including the drag values of the previous studies mentioned with the predictions of Equation 3.8a. The dependence of drag coefficient on A, defined as the ratio of the surface area to the projected area of the non-spherical particle. Large A denotes the low projected areas or large surface areas as observed in the case of needles and cylinders settling in vertical orientation. The deviations observed with the predictions of Renaud et al. (2004) with the predictions of the experimental data of the previous investigators (including the present data) are less compared to those observed with the other correlations.

It can be concluded here, by having a glance at the total average errors in Table 4.3 and the observations made from the graph that predictions made by using Equation 3.8 are in good agreement compared to the predictions made by others. From Table 4.2 it can also

Table 4.1: Summary of experimental data used in the study, in Newtonian media

Investigator	Shapes	N	Re	Sphericity
Unnikrishnan (1990)	Cylinders	52	0.1-167	0.59-0.95
Sharma (1991)	Cones	21	0.8-300	0.64-0.79
Venumadhav (1993)	Cylinders, Needles, Prisms	95	0.1-400	0.33-0.98
Tripathi et al. (1994)	Oblate and prolate spheroids	20	0.01-100	0.62-0.93
Borah (2004)	Cones	151	10^{-4}-400	0.66-0.79
Sabiri (2004)	Cylinders	22	0.01-0.3	0.626-0.86

Notations For Table 4.2:

A.E: Average Error; M.E: Maximum Error; T.A.E: Total Average Error

Table 4.2: Summary Of Results In Newtonian Media

	Chein (1994)		Ganser (1993)		and Luo (1987)		et al. (2004)		madhav (1993)		Equation 4.5	
	A.E	M.E	A.E	M.E	A.E	M.E	A.E	M.E	A.E	M.E	A.E	M.E
Unnikrishnan (1990)	58.9	78.9	45.9	73.1	47.9	81.7	49.3	76.2	45.3	73.6	42.5	74.5
Sharma (1991)	49.9	72.6	63.4	84.6	52.7	78.6	20.7	56.8	57.7	77.8	56.7	79.9
Venu Madhav (1993)	29.6	64.6	25.4	65.8	30.3	72.1	23.5	88.5	22.2	52.2	24.2	52.1
Tripathi et al.(1994)	21.3	57.3	1.2	15.2	58.5	79.4	34.5	62.1	38.9	65.6	37.3	61.5
Borah (2004)	46.7	74.6	42.9	73.2	63.5	123.1	36.5	67.2	19.1	42.5	38.2	68.8
Sabiri (2004)	40	75.3	40.7	68.4	43.2	67.4	14.5	34.5	34.8	5.8	38.8	73.1
Present values	30	71.5	25.8	70.4	44.9	73.2	33.9	52.3	26.6	73.2	27.4	79.5
T.A.E	39.5	70.7	35.08	64.4	48.6	82.2	38.7	62.5	36.3	63.2	37.6	69.6

be observed that the agreement between the experimental drag values for cylinders (settling in vertical orientation) and the predictions by Venumadhav (1993) is reasonable.

4.2.1.3. Settling Velocity Ratio

As discussed in the third chapter, the second approach of correlating the settling data for non spherical particles with that of spherical particle, the following expression was found to be useful by Singh and Roychoudhury (1969).

$$K=a\left(\frac{d_{eq}}{d_n}\right)\psi^{0.5}+b\left(\frac{d_{eq}}{d_n}\right)^2\psi+c \tag{4.8}$$

Where, K is defined as the ratio of settling velocity of the non spherical particle to that of the spherical particle of same volume. The velocity of spherical particle was found from Eq.3.8. Heiss and Coull (1952) proposed the following equations for settling velocity ratio for a non-spherical particle settling in horizontal orientation (axis of the object perpendicular to the motion of fluid), in Equation 4.10. Equation 4.11 predicts the settling velocity ratio for a non-spherical particle settling in vertical orientation (axis of the object parallel to the direction of fluid flow).

$$\log_{10}(K_h)=\left[-0.25\sqrt{\psi\frac{d_{eq}}{d_n}}\left(\frac{d_{eq}}{d_n}-1\right)+\log_{10}\left(\frac{d_{eq}}{d_n}\sqrt{\psi}\right)\right] \tag{4.9}$$

$$\log_{10}(K_v)=\left[\frac{-0.27}{\sqrt{\psi}\left(\frac{d_{eq}}{d_n}\right)^{0.345}}\left(\frac{d_{eq}}{d_n}-1\right)+\log_{10}\left(\frac{d_{eq}}{d_n}\sqrt{\psi}\right)\right] \tag{4.10}$$

The equations presented above can be used in the range creeping flow region only. The experimentally estimated K is compared with the predictions of Heiss and Coull (1952). The match between the two is seen to be satisfactory with the average and maximum deviations 24.2% and 73.13% respectively. Venumadhav (1993) proposed the following correlation, for the estimation of settling velocity ratio, K, for cylinders settling in vertical orientation in a Newtonian fluid in the range of Reynolds number, $0.1 \le Re \le 400$.

$$K=0.185\left(\frac{d_{eq}}{d_n}\right)\psi^{0.5}+0.00576\left(\frac{d_{eq}}{d_n}\right)^2\psi+0.417. \quad (4.11)$$

The match between the two is observed to be agreeable with the average 32.7% and maximum deviations 73.8% respectively.

In this work, an overall correlation for K with the combined experimental observations of Venumadhav (1993), Unnikrishnan (1990), Sabiri (2004) including the present experimental results, for cylinders settling in both orientations is attempted. Using regression analysis, the following equation is developed for settling velocity ratio, K:

$$K=0.052\left(\frac{d_{eq}}{d_n}\right)\psi^{0.5}+0.115\left(\frac{d_{eq}}{d_n}\right)^2\psi+0.364 \quad (4.12)$$

The predictions of Equation 4.12 are compared with the experimental values of K estimated from previous experimental data of Venumadhav (1993), Unnikrishnan (1990) and Sabiri (2004) data. The agreement seems to be satisfactory with the overall average and maximum deviations 23.2% and 72.3 % respectively.

4.2.2 Non-Newtonian Media

4.2.2.1 Drag Results

Same approach is used to analyse the settling velocity data as is done for Newtonian media. The Reynolds number is calculated from the known terminal velocities as defined by Equation 3.6. It is observed that the Reynolds number varied from 10^{-6} to 267, thereby covering 8 decades of variation. The behavior of slope of the drag curve is seen to be unchanged from that observed in Newtonian fluids. Drag coefficient is calculated as a function of Reynolds for each fall test, is shown in Figure 4.9. The nature of dependence of drag coefficient on Reynolds number and orientation is seen to be the same as found in Newtonian media.

Further verification of the experimental drag values is done by comparing with the correlation proposed by Venumadhav (1993).He developed the following correlation for drag on cylinders, needles and rectangular prisms settling in vertical orientation, in non-Newtonian media.

$$C_D = \frac{32.5}{Re}\left(1+2.5Re^{0.2}\right), \quad 2\times10^{-4} \leq Re \leq 145 \tag{4.13}$$

The data on settling of cylinders in vertical orientation is separated from that observed in horizontal orientation to compare with Equation 4.15. The comparison of the present experimental drag values with the predictions made by Venumadhav (1993) is presented in Figure 4.9. The present experimental drag values on settling of cylinders in vertical orientation are seen to match well with the predictions made by Equation 4.15 with the average and maximum deviations 26.6% and 72.3% respectively.

The following Equation for drag is found by regression analysis from 914 data points, for settling of cylinders in both orientations, for the entire range of Reynolds number encountered in the experiments.

$$C_D = \frac{28.35}{Re}\left(1+2.92Re^{0.27231}\right), \quad 10^{-6} \leq Re \leq 267 \tag{4.14}$$

With the average and maximum deviations 27.46% and 78% respectively, it can be concluded here; that the agreement between the experimental drag coefficient and those predicted by the correlation proposed is satisfactory and acceptable. Figure 4.10 presents the comparison of experimental drag coefficient with the predictions of Equation 4.16.

4.2.2.2 Analysis Of The Previous Works

Previous studies of Venumadhav (1993), Unnikrishnan (1990), Sabiri (2004), Borah (2004) and Sharma (1991) and numerical work by Tripathi et al. (1994) on oblate and prolate spheroids are analysed in the same way as done in Newtonian media. The same approach is continued here by comparing the present experimental results on settling of cylinders in non-Newtonian media, including the previous studies by the investigators mentioned with the correlations proposed by Venumadhav (1993), Peden and Luo (1987) and Renaud et al. (2004). The details of their experimental work are summarized in Table 4.3.

Peden and Luo (1987) proposed the following correlation for drag, for settling of non-spherical particles in power-law fluids.

$$C_D = F_S C_{D,S} = \frac{F_S a}{Re^e}, \tag{4.15a}$$

$C_{D,S}$ is the drag coefficient of an equal volume sphere.

In laminar flow regime,

$$a = 39.8 - 9n, \tag{4.15b}$$

and

$$e = 1.2 - 0.47n \quad \text{for} \quad Re \leq 5 \text{ and } n \geq 0.45 \tag{4.15c}$$

In transition flow regime,

$$a = 42.9 - 23.9n \tag{4.15d}$$

and

$$e = 1 - 0.33n \text{ and } 1 \leq Re \leq 200 \tag{4.15e}$$

The experimental drag coefficients of Venumadhav (1993), Unnikrishnan (1990), Sabiri (2004), Borah (2004) and Sharma (1991) and Tripathi et al. (1994) with the predictions made by Peden and Luo (1987) are presented in Figure 4.11. From Equation 4.15a to 4.15e it can be seen the predictions of drag coefficient are presented as function of sphericity of the test particle, power law index of the test fluid apart from Reynolds number. The solid line n=0.45 includes the experimental drag coefficients calculated for particle corresponding to the power la index in the range of ±0.075 from that mentioned in the figure. The deviations involved are summarized in Table 4.4.

Renaud et al. (2004) proposed Equation 3.8a for drag on settling of non-spherical particles in both Newtonian and non-Newtonian media. Figure 4.12 shows the comparison of the present experimental results including the prior studies mentioned above with the drag predictions of Renaud et al. (2004). The average deviations involved are presented in Table 4.4 along with the deviations observed with the other correlations used.

From the deviations observed in Table 4.4, it can be concluded that the correlation proposed by Venumadhav (1993) is better applicable for cylinders in vertical orientation. The total average errors in Table 4.4 reveal that the predictions of Renaud et al. (2004) are reasonable compared to those by Peden and Luo (1987). Equation 4.14 suited well with the experimental drag values corresponding to cylindrical particles settling in both horizontal and vertical orientation, there by suggesting the applicability of the correlations used and the reliability of the experimental data.

4.2.2.3 Settling Velocity Ratio

As discussed in section 3.5, in the second approach of the analysis of the settling data, the terminal velocity measurements are represented and correlated in terms of a velocity ratio. The terminal velocity of the equal volume sphere is predicted from the correlation proposed by Renaud et al. (2004), thus the settling velocity ratio is estimated for each fall.

The dependence of K on the shape factors is in the same form as found in Newtonian fluids. The coefficients of the most probable form of the settling velocity ratio are found by regression analysis.

$$K = 0.114\left(\frac{d_{eq}}{d_n}\right)\psi^{0.5} + 0.093\left(\frac{d_{eq}}{d_n}\right)^2 \psi + 0.145 \qquad (4.16)$$

The agreement between the predictions of Equation 4.16 with the settling velocity ratio found using the present experimental data seems to be acceptable with the average and maximum deviations 26.9% and 70.5% respectively.

4.3 Observations

4.3.1 Newtonian Media

It is observed that the orientation is a strong function of Reynolds number, concentration of the test fluid and physical properties (aspect ratio, density) of the test particle. In most instances the ultimate orientation of the settling object was vertical in dilute glucose solutions (where large Reynolds numbers are encountered) independent of its initial

Table 4.3: Summary of experimental data used in the study, in Non-Newtonian media

Investigator	Shapes	N	Re	Sphericity	n
nnikrishnan (1990)	Cylinders	41	0.01-1.7	0.59-0.95	0.48-0.61
Sharma (1991)	Cones	24	0.01-36	0.64-0.79	0.3-0.85
enumadhav (1993)	Cylinders, Needles, Prisms	190	0.1-140	0.33-0.98	0.77-0.96
pathi et al. (1994)	Oblate and Prolate Spheroids	80	0.01-100	0.62-0.93	0.4-0.8
Borah (2004)	Cones	144	10-113	0.66-0.94	0.4-0.72
Sabiri (2004)	Cylinders	40	0.01-1.6	0.626-0.86	0.31-0.86

Notations For Table 4.4:

A.E: Average Error; M.E: Maximum Error; T.A.E: Total Average Error

'able 4.4: Summary Of Results In Non-Newtonian Media

	and Luo (1987)		et al. (2004)		dhav (1993)		Equation 4.17	
	A.E	M.E	A.E	M.E	A.E	M.E	A.E	M.E
Unnikrishnan (1990)	39.6	67.4	29.3	67.8	40.2	75.6	42.5	74.3
Sharma (191)	21.07	65.9	25.4	54.3	61.4	73.4	55.6	78.9
Venu Madhav (1993)	33.16	58.3	50.5	76.9	29.74	64.7	26.4	60.5
Tripathi et al.(1994)	23.89	59.8	20.7	45.8	60.7	76.4	62.7	80.3
Borah (2004)	35.4	97.4	22.2	78.3	65.2	85.5	64.4	82.5
Sabiri (2004)	13.8	32.6	8.5	28.9	66.8	76.9	60.5	71.3
Present values	44.9	58.5	30.9	80.5	26.6	65.7	27.4	56.7
T.A.E	33.5	62.84	27.32	61.79	50.1	74.03	48.1	72.07

orientation, in Newtonian media. The rate of change of the orientation is seen to be strongly dependent on the aspect ratio, as it is observed that the discs are turning to vertical orientation much more quickly than the other cylinders. At moderate Reynolds numbers, the ultimate orientation is observed to be horizontal for all the particles. Settling velocity ratio K, is observed to be dependent on the orientation, this can be understood as the settling phenomenon of a non spherical particle is a strong function of orientation. Settling velocity ratio calculated for vertical orientation is found to be much greater than that calculated for horizontal orientation.

4.3.2 Non-Newtonian Media

The orientation is seen to be dependent on the power-law index of the test fluid and aspect ratio of the test particle apart from relative density between the settling object and the test fluid. The rate of change of the orientation is much higher for discs, and is seen to increase with the shearthinning behavior of the test fluids for all the range of Reynolds number. The settling velocity ratio showed the same trend as observed in Newtonian media.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Free settling velocity of regular but non-spherical particles in a variety of Newtonian and non-Newtonian fluids has been measured. Wide range of Reynolds number was covered during experiments. The data is analysed in two ways, the first method is, by correlating the steady state drag coefficient with the Reynolds number, both based on equivalent volume sphere diameter. The experimental drag coefficients are compared with the existing correlations for non spherical particles. The match between the two is found to be agreeable, thus signifying the reliability of the present experimental data. Extensive analysis has been carried out on the experimental results available in the literature, by comparing with the correlations present in the literature on settling of spherical and non spherical particles in Newtonian and non-Newtonian media.

Based on the present experimental records, correlations have been proposed for drag on cylindrical particles settling in both the orientations, in Newtonian and non-Newtonian media, thus fulfilling the first objective of this work. The correlations proposed are seen to satisfy the current experimental results with reasonable level of accuracy. The experimentally recorded velocities were verified with the predictions of Hartman et al. (1994), in both Newtonian and non-Newtonian media. It is found that the accuracy of the experimental measurements of velocity is good. From the observations made on the change in orientation during settling, it is seen that the ultimate orientation depends on the Reynolds number, aspect ratio of the test particle and rhelogical properties of the test media. At high Reynolds numbers the particles were ultimately settling in vertical orientation. The rate of change of orientation was observed to increase with the increase in the shearthinning properties of the test fluid.

In the second approach of analyzing the settling velocity data, the behavior of a non spherical particle is contrasted with that of an equal volume sphere and some other geometrical ratios characterizing the shape in relation to a sphere. It is observed that the settling velocity ratio is a strong function of the orientation apart from the shape factors of the settling object, due to the obvious reason that the settling characteristics of a non-spherical particle depend on its orientation. Two correlations were proposed separately

for cylinders settling in horizontal and vertical orientations, separately in Newtonian and non-Newtonian fluids. Good agreement is found between the predictions of these correlations with the experimental results of Venumadhav (1993), Unnikrishnan (1990) and unpublished work of Sabiri (2004), including the present experimental results of settling velocity ratio, thus fulfilling the second objective of the present work.

5.1 Recommendations for future work

There is a lot of scope for both numerical and experimental study in this area. The objectives of future research can be some of the following mentioned points.

1. The settling phenomenon greatly depends on the nature of the settling media; here the effect of shearthinning behavior on the settling of cylinders has been studied.

The research can be continued to study the effect of other non-Newtonian characteristics of settling media like shear thickening, visco-elasticity, etc.

2. Experiments can be carried out for the study on the settling of fibrous suspensions, where the present experimental observations can be used.

3. Research must be carried out for better characterization of non spherical particles. The applicability of effective diameter must be tested in future works.

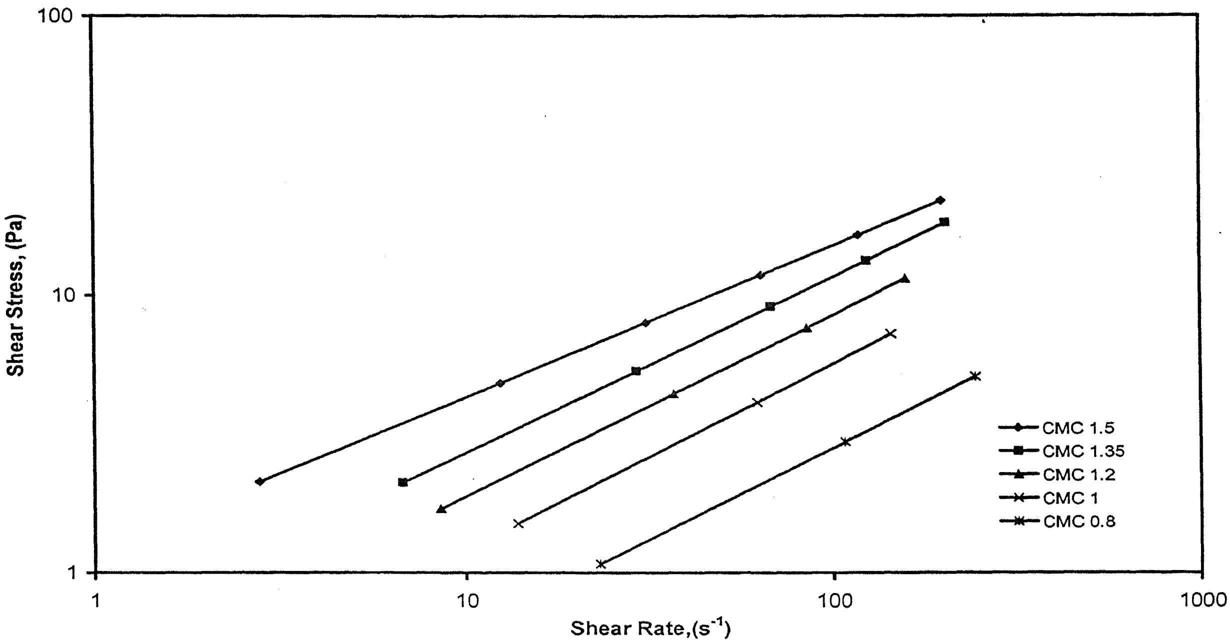

Figure 4.1: Typical shear stress-shear rate data for CMC polymer solutions of different concentrations

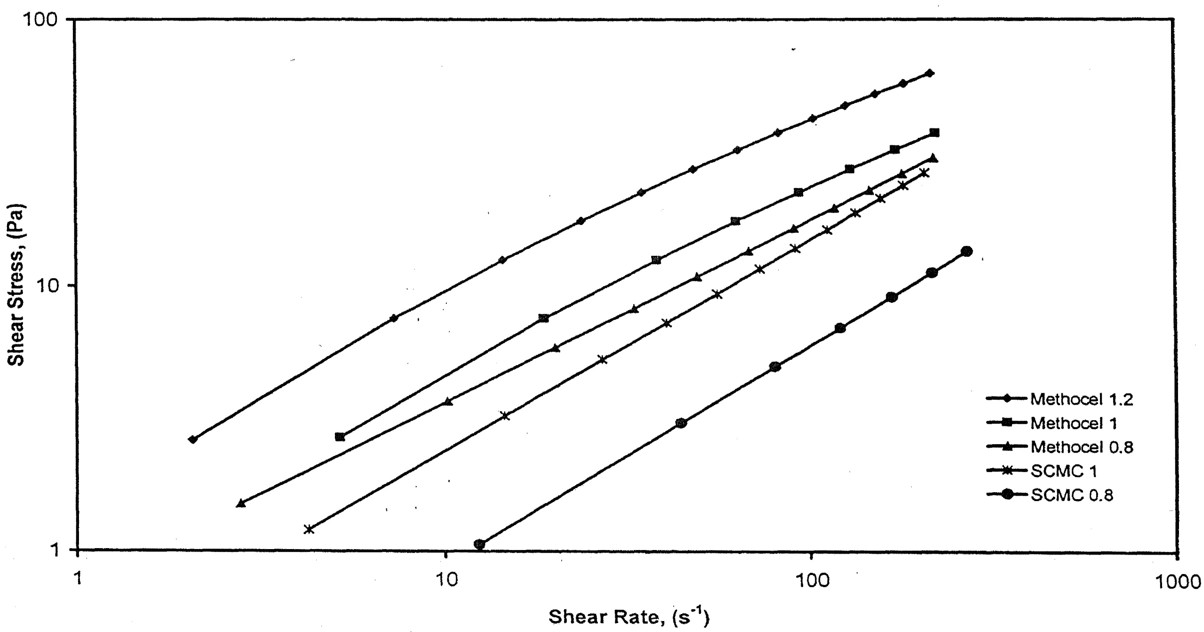

Figure 4.2 :Typical shear stress-shear rate data for aqeous Methocel and Sodium CMC solutions of different concentrations

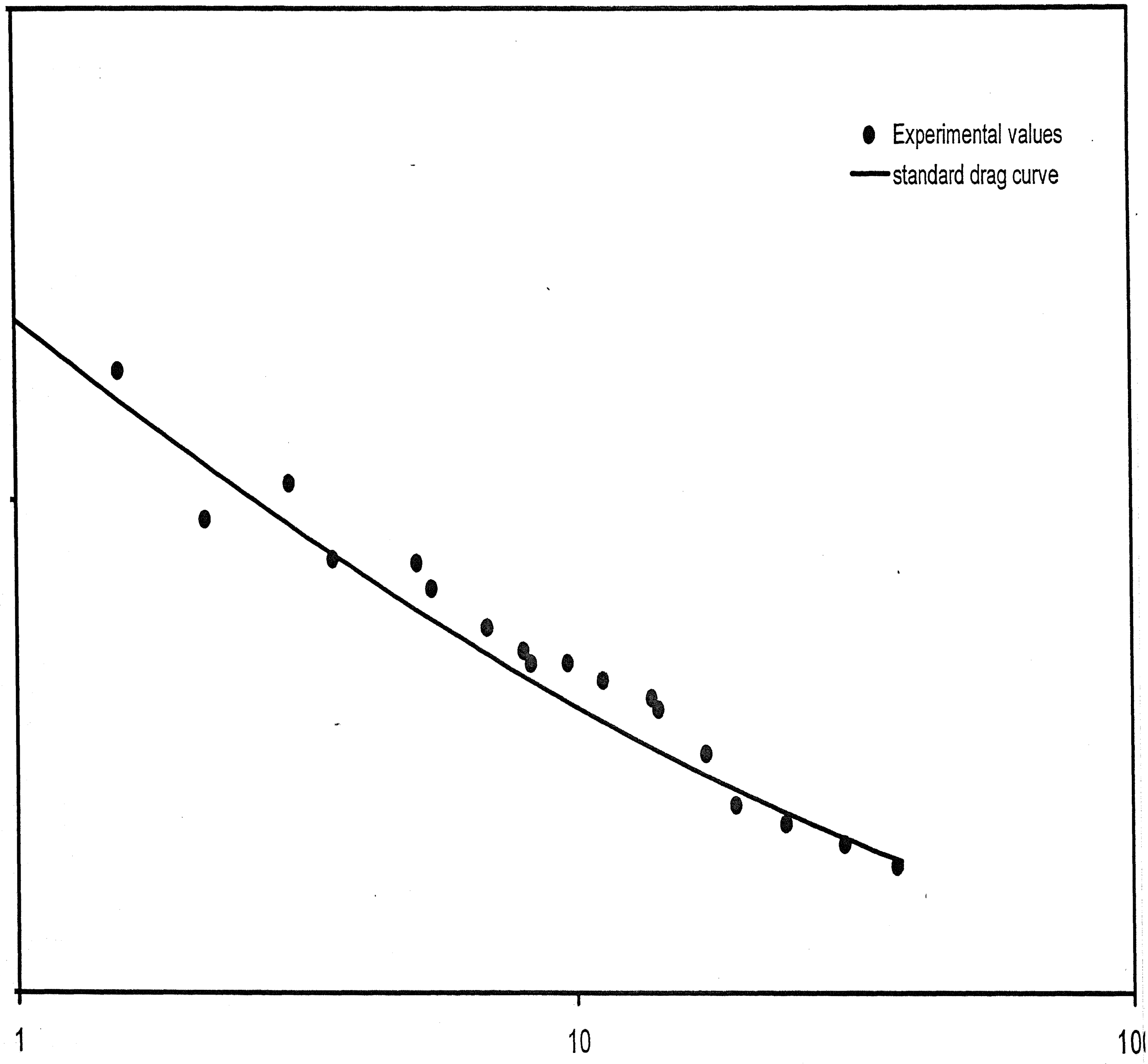

Figure 4.3: Comparison of the present values of C_D with the literature results for spheres

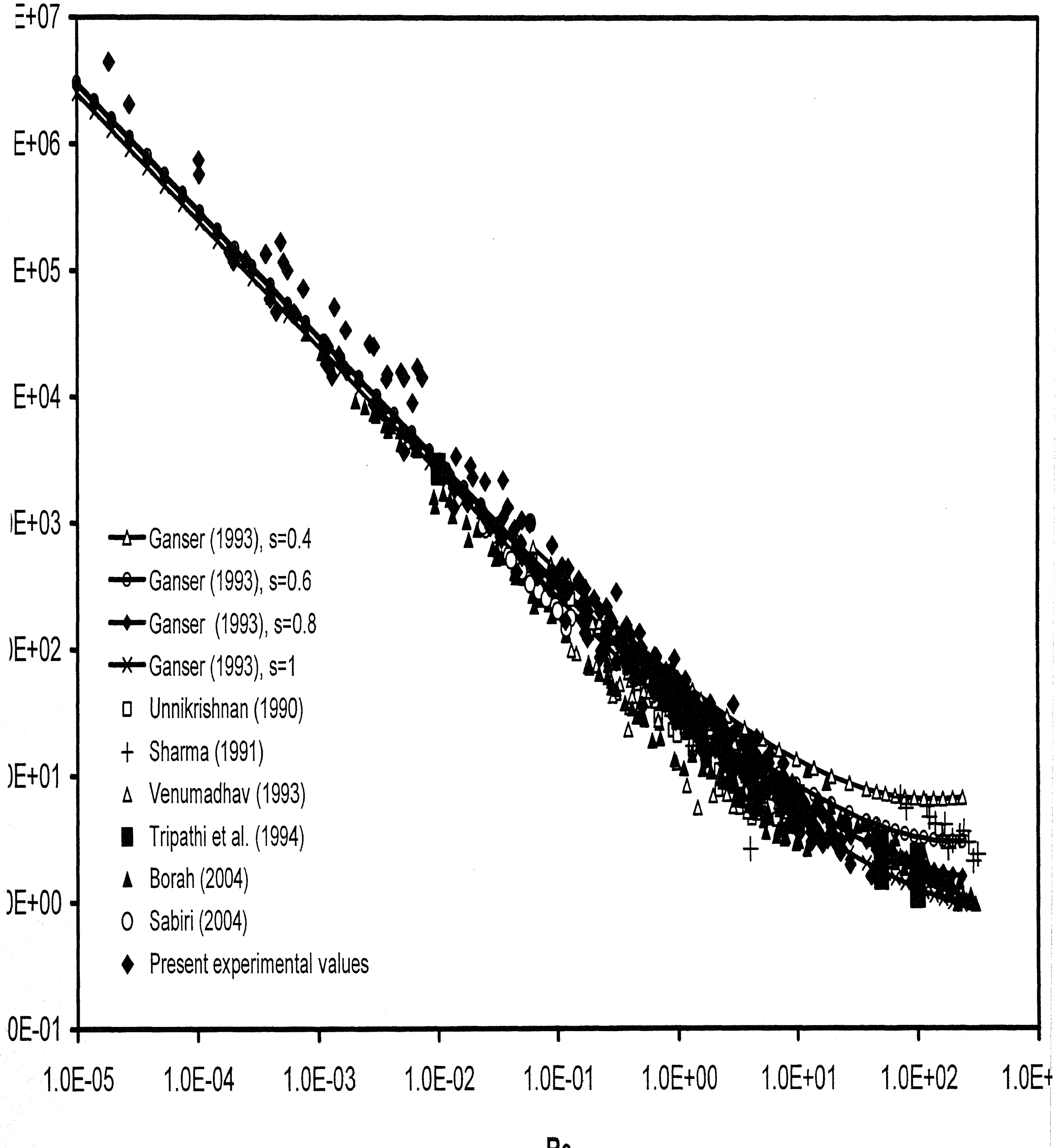

Figure 4.4: Comparison of the experimental drag coefficients with the predictions by Ganser (1993)

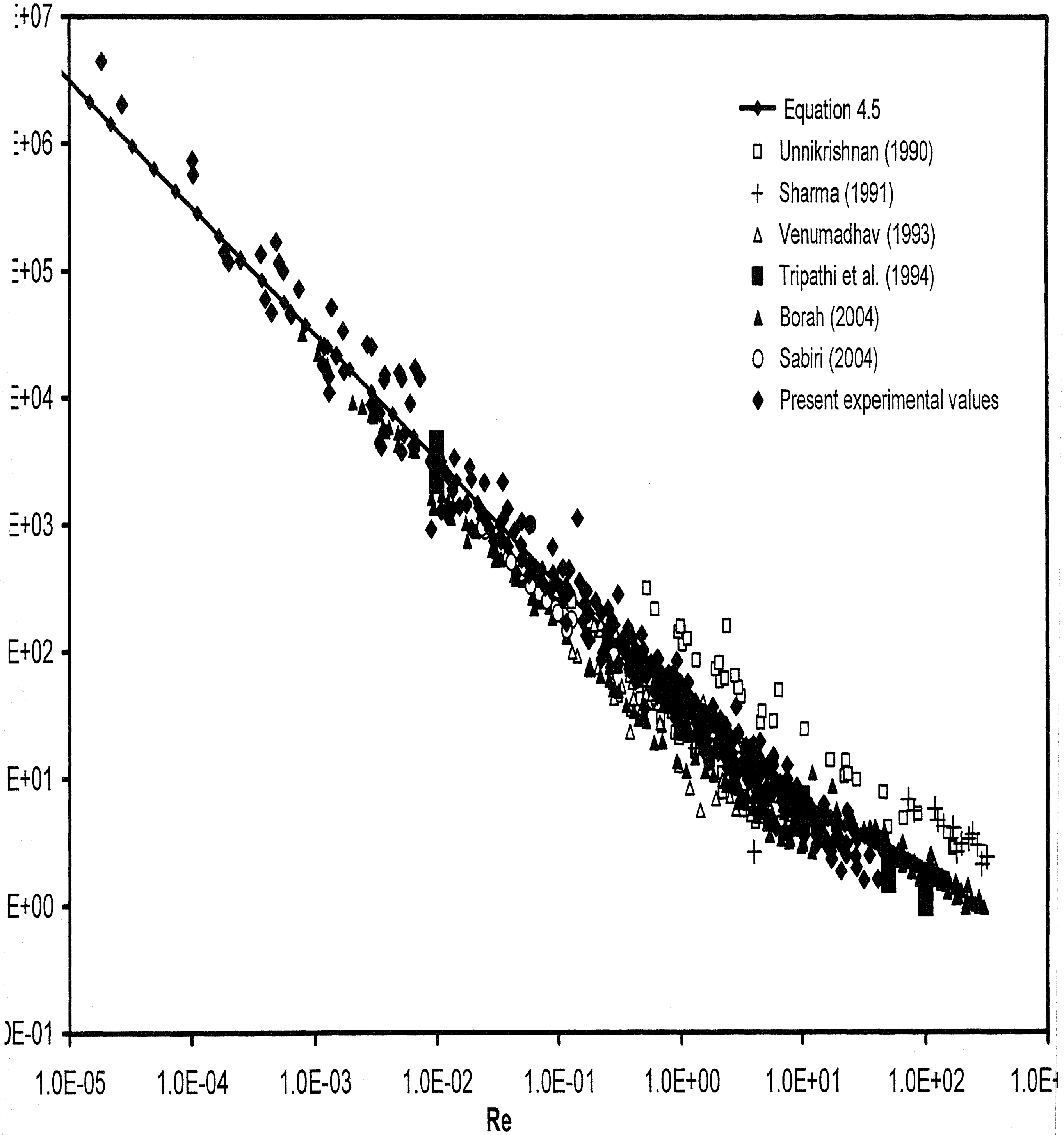

Figure 4.5 : Comparison of the experimental values with the predictions of the correlation found for particles settling in Newtonian media

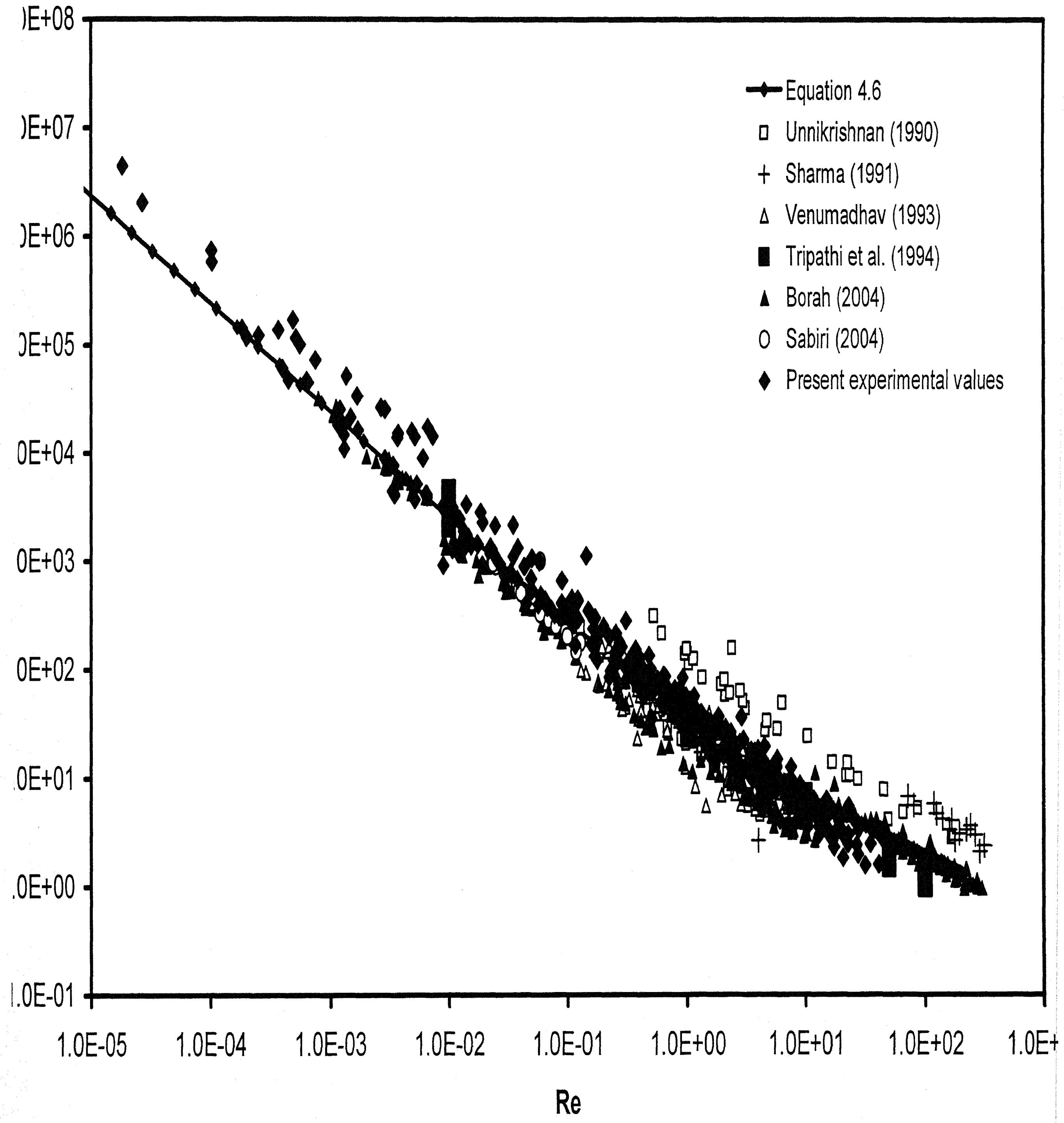

Figure 4.6: Comparison of the experimental drag values with the predictions by Venumadhav (1993) in Newtonian media

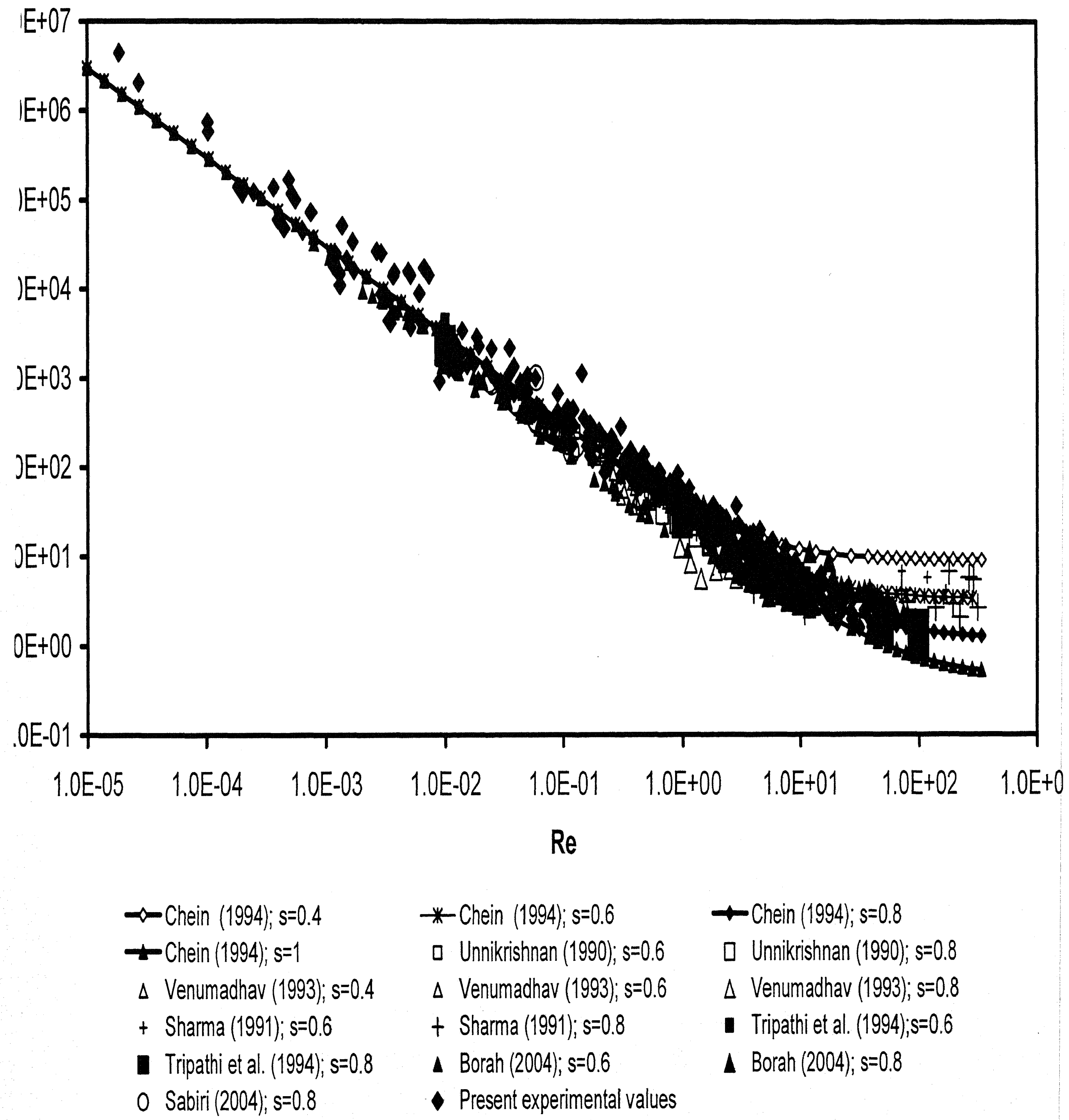

Figure 4.7:Comparison of the experimental darg coefficients with the predictions made by Equation 4.7

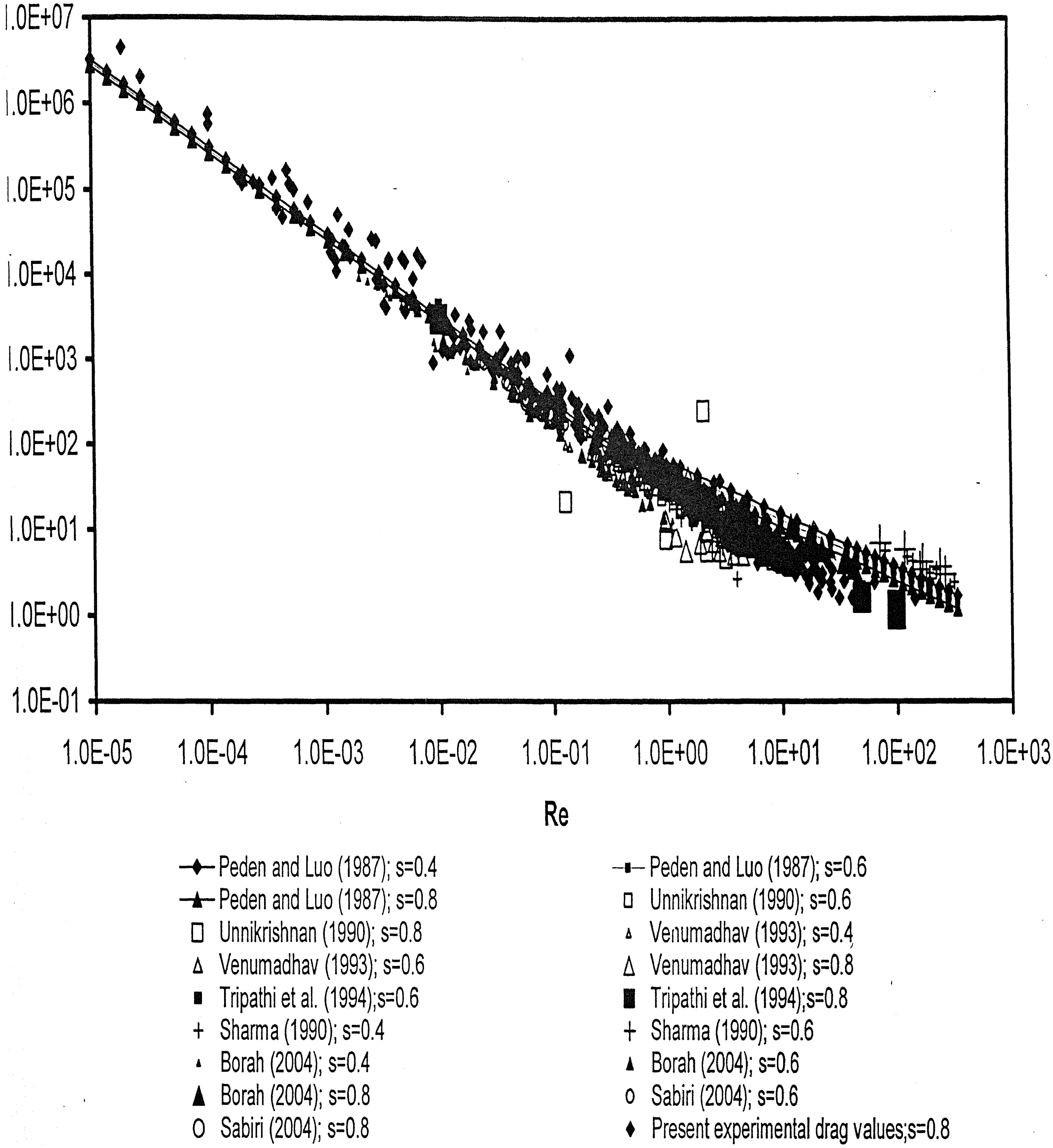

Figure 4.8: Comparison between the predictions of Peden and Luo (1987) with the experimental drag values in Newtonian media.

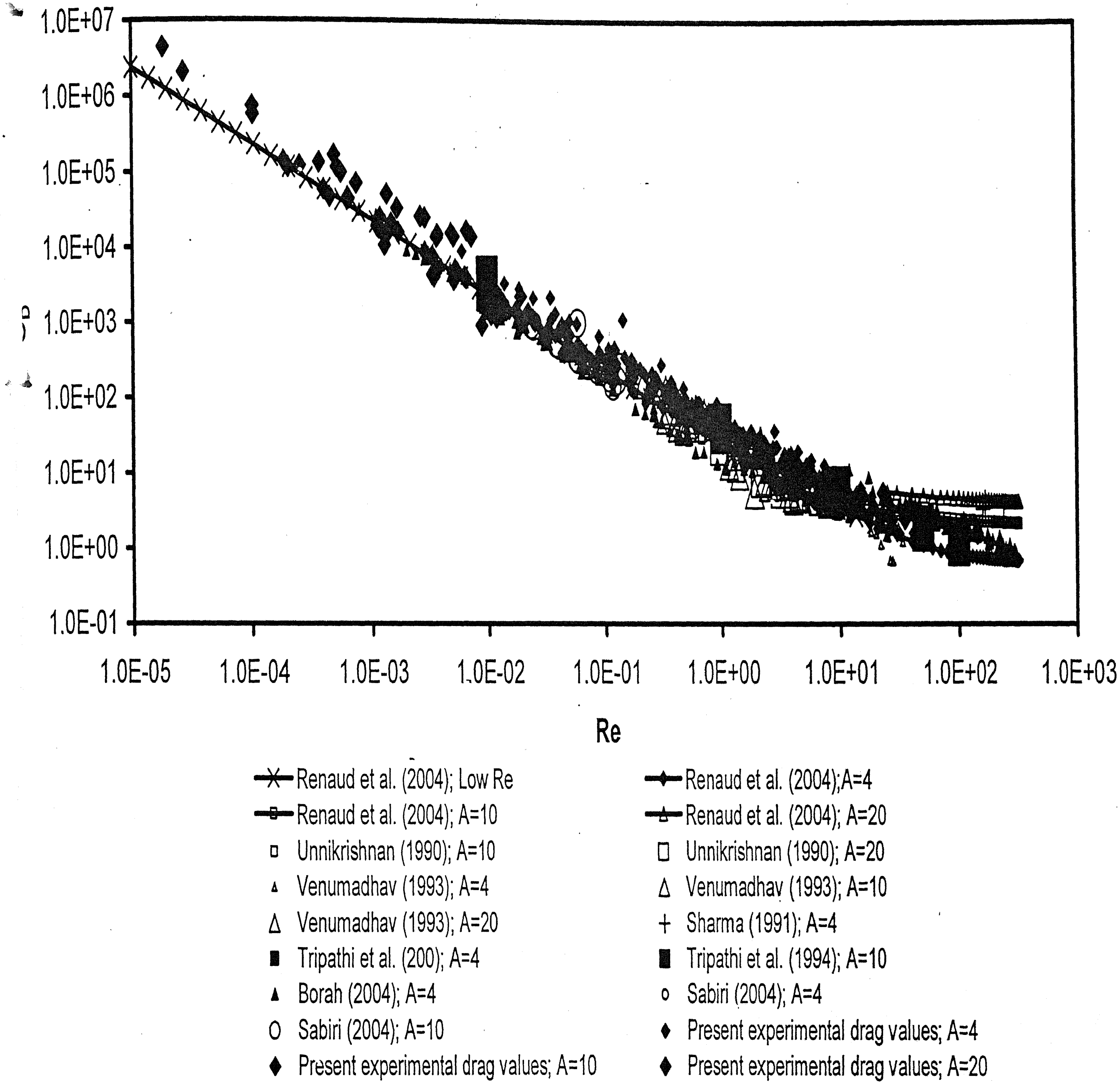

Figure 4.8: Comparison between the predictions of Renaud et al. (2004) with the experimental drag coefficients in Newtonian media

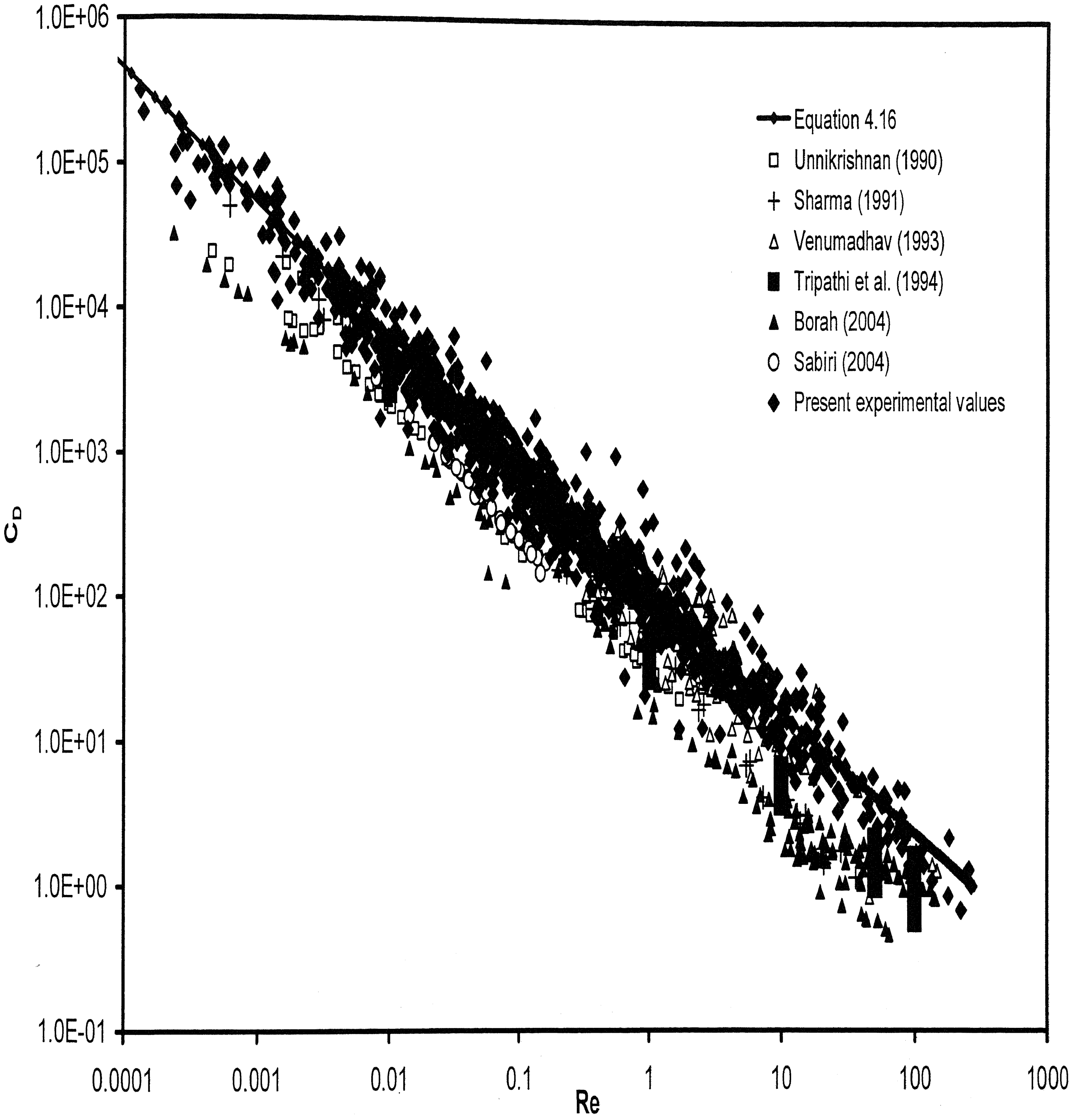

Figure 4.9: Comparison of the experimental values with the predictions made by Venumadhav (1994)

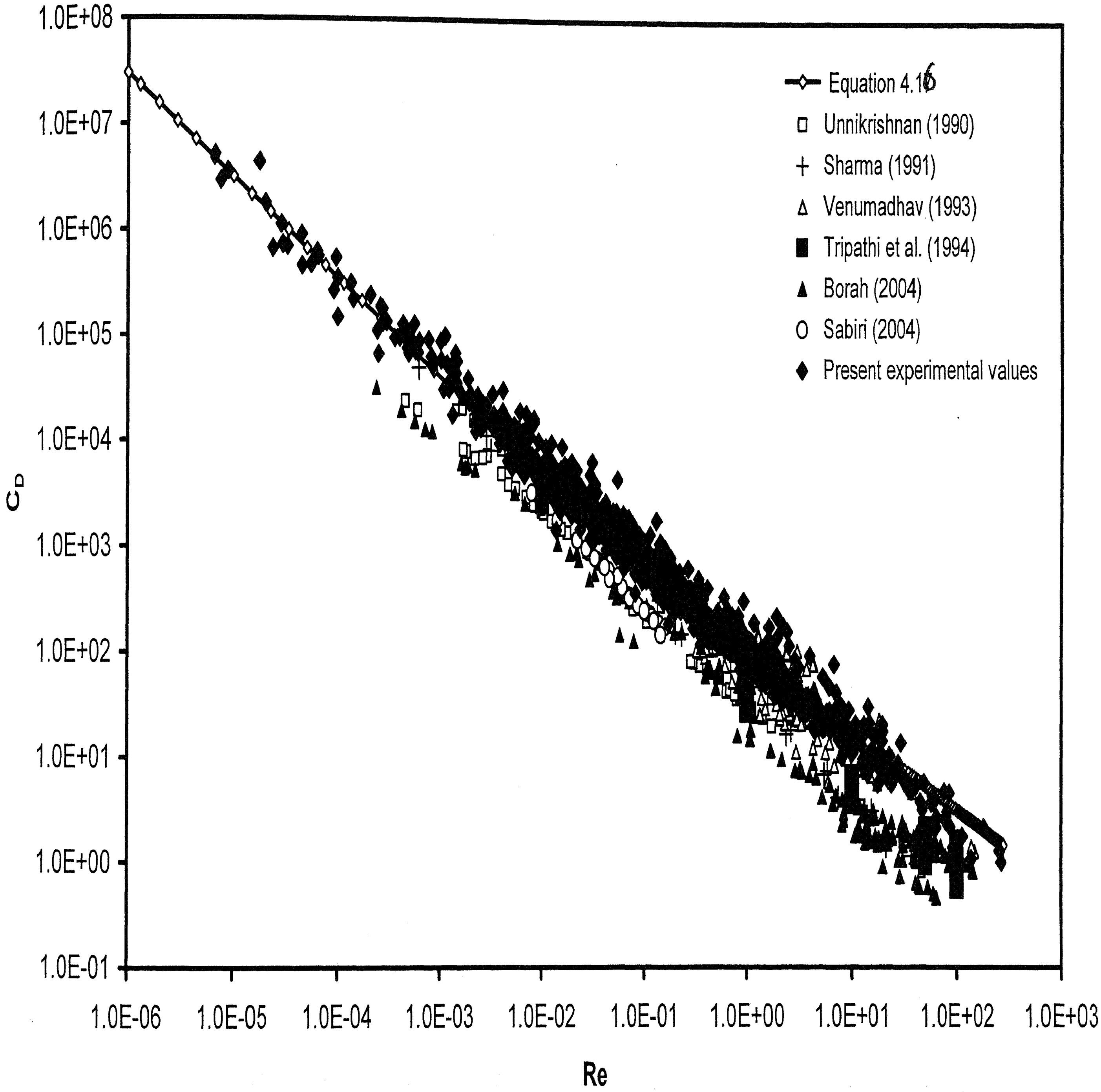

Figure 4.10:Comparison of the present experimental drag values with the predictions of Equation 4.16

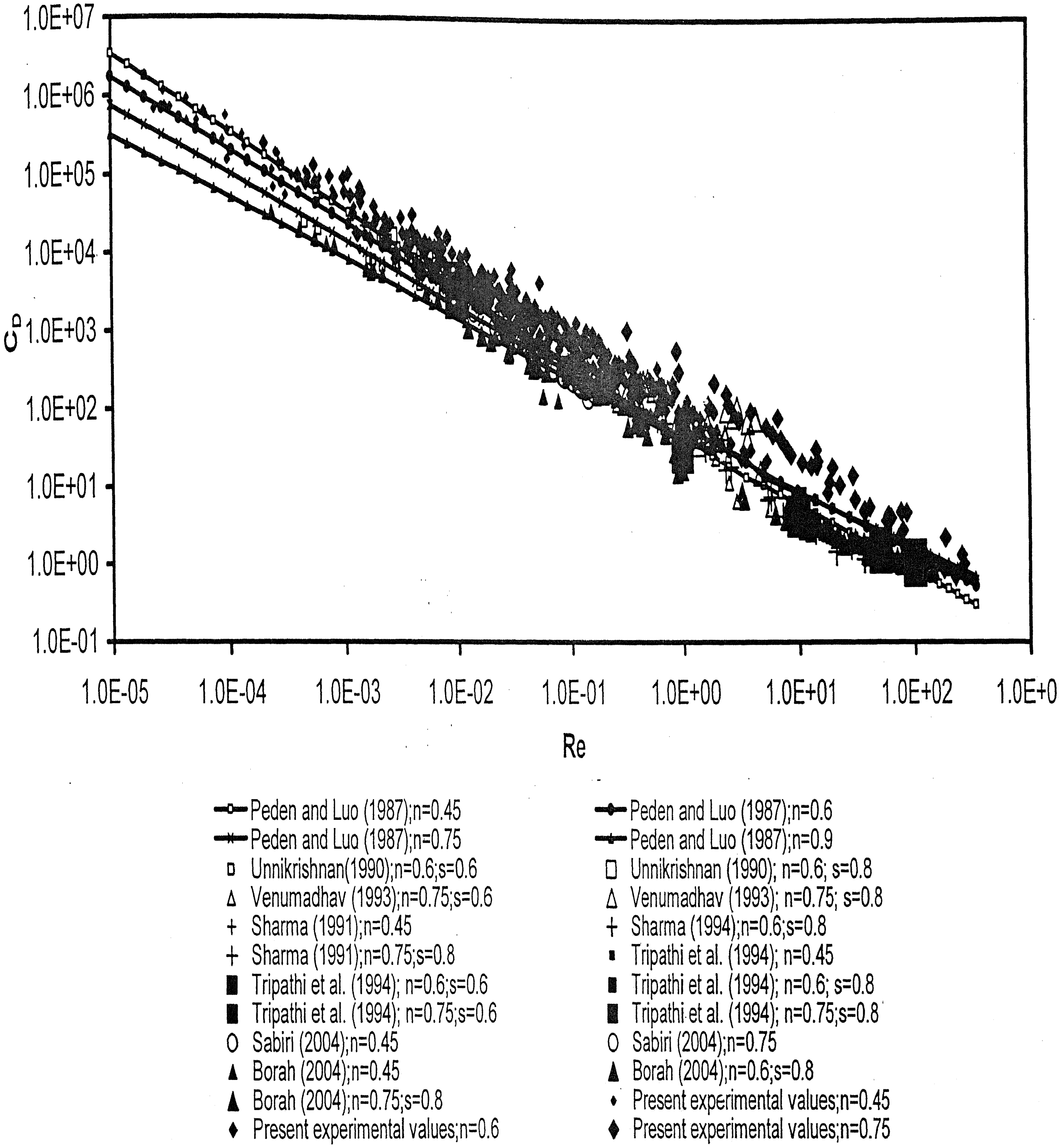

Figure 4.11: Comparison between the predictions made by Peden and Luo (1987) with the experimental drag values in non-Newtonian media

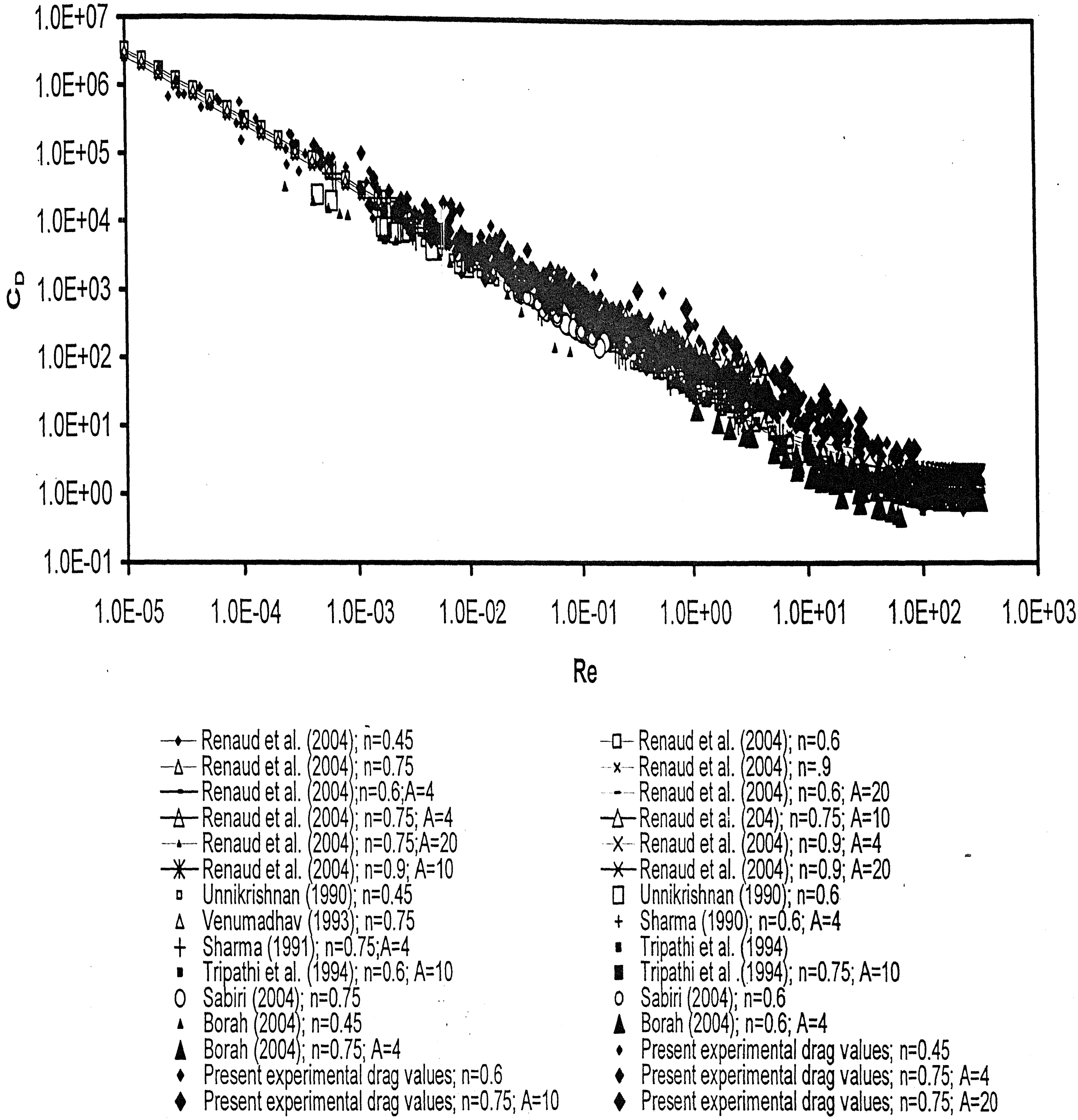

Figure 4.12: Comparison between the experimental drag coefficients with the predictions of Renaud et al. (2004) in non-Newtonian media.

Nomenclature

A	Surface area of a particle (m^2).
A_s	Specific surface area of a particle (m^{-1}).
A_p	Projected area of a particle (m^2).
a	Coefficient defined in Eq. 4.8a
C_D	Drag coefficient.
d	Diameter of the particle (mm) .
d_{eq}	Equivalent volume sphere diameter (mm).
d_n	Diameter of a sphere having same projected area as that of the non-spherical particle (mm).
e	Coefficient defined in Eq. 4.8a
F_D	Drag force on the particle (N).
F_s	Shape factor of particles (for spheres, $F_s = 1$).
g	Acceleration due to gravity (m/s^2) .
k	Consistency index of power law fluids ($Pa.s^n$).
K	Settling velocity ratio.
K_1, K_2	Shape factors in low and high Reynolds number regions, respectively, Eq.4.4a to Eq. 4.4 c
n	Flow behavior index of power law fluids.
Re	Reynolds number based on Equivalent volume sphere diameter.
V_t	Terminal velocity of the particle (mm/s).
V	Volume of the particle (mm^3).

Greek Symbols

ψ	Sphericity of the non-spherical particle.
μ	Viscosity of the Newtonian fluid (Pa.s).
ρ_f	Density of the test fluid (kg/m^3).

ρ_p	Density of the particle (kg/m^3).
τ	Shear stress (Pa).
$\dot{\gamma}$	Shear rate (s^{-1}).

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APPENDICES

Predictions Of Velocity

APPENDIX I A: Cylinders Settling In Horizontal Orientation In Newtonian media

Units : Velocity, m/s

Notations: $V_t(H)$: Velocity predicted By Hartman et al. (1994).

Re(H): Reynolds Number Predicted By Hartman et al.(1994).

Test Fluid 1 : Glucose 87.5% Solution; $\mu = 1.28$ Pa.s; $\rho_f = 1375\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	0.91	0.696	0.058	0.045	23.52
A2	0.74	0.625	0.035	0.030	15.54
A3	0.613	0.551	0.023	0.021	10.19
A5	5.14	4.325	0.651	0.548	15.87
A6	4.034	4.154	0.377	0.389	-2.96
A7	3.14	3.613	0.233	0.268	-15.08
A9	7.033	5.123	1.182	0.861	27.15
A10	6.4	6.158	0.793	0.763	3.78
A11	4.1	4.020	0.404	0.396	1.94
A13	11.4	8.445	2.415	1.789	25.92
A14	9.5	8.858	1.482	1.382	6.76
A15	7.62	8.025	0.943	0.993	-5.31

Test Fluid 2 : Glucose 75% Solution; $\mu = 0.54$ Pa.s; $\rho_f = 1230\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	3.14	2.590	0.428	0.353	17.53
A2	2.54	2.570	0.255	0.258	-1.17
A3	2.1	2.408	0.168	0.193	-14.69
A4	1.03	1.063	0.065	0.068	-3.25
PC9	3.75	2.805	1.336	1.000	25.21
PC10	2.34	1.936	0.615	0.509	17.25
PC11	1.717	1.543	0.359	0.322	10.16
PC12	0.738	0.563	0.123	0.094	23.71
PC13	4.85	3.282	2.178	1.474	32.32
PC14	3.2	2.437	1.059	0.806	23.84
PC15	2.15	1.709	0.564	0.448	20.52
G1	7.27	5.480	1.728	1.303	24.62
G2	6.5	4.923	1.461	1.107	24.26
G3	6.15	4.853	1.304	1.029	21.08
G4	5.6	4.509	1.116	0.899	19.49
G5	4.16	3.048	0.786	0.576	26.73
G6	3.8	2.956	0.653	0.508	22.22
G7	3.3	2.727	0.498	0.411	17.36
G8	2.2	1.777	0.284	0.229	19.24
G9	9.32	6.341	2.780	1.892	31.96
G10	8.55	6.022	2.388	1.682	29.57

G11	7.58	5.413	1.974	1.410	28.59
G12	6.62	4.976	1.544	1.161	24.83
G13	5.86	4.327	1.307	0.965	26.17
G14	4.72	3.365	0.978	0.698	28.70
G15	4.38	3.312	0.824	0.623	24.37

Test Fluid 3 : Glucose 72% Solution; $\mu = 0.4$ Pa.s; $\rho_f = 1100\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	3.82	2.774	0.628	0.454	27.39
A2	2.8	2.462	0.340	0.297	12.06
A3	1.7	1.462	0.165	0.141	14.00
A4	1.23	1.159	0.094	0.088	5.79
A5	11.5	7.616	3.729	2.457	33.77
A6	8.12	6.101	1.945	1.454	24.86
A7	7.12	6.331	1.351	1.195	11.09
A8	4.375	3.850	0.659	0.577	12.00
PC9	4.85	3.251	2.087	1.392	32.98
PC10	3.94	3.294	1.250	1.040	16.40
PC11	2.92	2.658	0.736	0.667	8.98
PC12	2.26	2.291	0.454	0.458	-1.38
PC13	7.82	5.516	4.240	2.976	29.46
PC14	5.95	4.927	2.377	1.958	17.20

PC15	4.35	3.848	1.378	1.213	11.53

Test Fluid 4: Glucose 50% Solution; $\mu = 0.204$ Pa.s; $\rho_f = 1050\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	7.5	4.409	2.308	1.318	41.21
A2	6.15	4.945	1.396	1.090	19.59
A3	3.84	3.149	0.696	0.554	17.99
A4	2.35	1.900	0.337	0.265	19.17
G1	20.5	15.001	11.010	7.827	26.82
G2	18.5	13.423	9.398	6.624	27.44
G3	17.04	12.551	8.166	5.843	26.34
G4	16.511	12.900	7.436	5.644	21.87
G5	15.85	12.852	6.771	5.333	18.92
G6	14.17	11.968	5.499	4.512	15.54
G7	12.52	11.281	4.266	3.734	9.90
G8	9.104	7.831	2.652	2.216	13.99
G9	26.2	19.855	17.660	13.001	24.22
G10	22.1	15.637	13.946	9.586	29.24
G11	18.33	12.152	10.788	6.948	33.70
G12	14.15	8.866	7.458	4.540	37.34
G13	11.5	6.615	5.795	3.238	42.48
G14	9.66	5.393	4.525	2.454	44.18
G15	6.72	3.355	2.857	1.386	50.07

Test Fluid 5 : Glucose 40% Solution; $\mu = 0.154$ Pa.s; $\rho_f = 1000\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	12.35	10.404	4.796	4.040	15.76
A2	9.5	9.275	2.720	2.656	2.37
A3	7.34	7.762	1.678	1.774	-5.74
A4	3.5	3.199	0.634	0.580	8.60
A9	24.5	14.251	24.891	14.479	41.83
A10	21.5	14.495	16.111	10.862	32.58
A11	17.5	12.509	10.420	7.449	28.52
A13	35.5	24.788	45.452	31.737	30.17
A14	29.31	20.838	27.645	19.654	28.91
A15	26.5	21.276	19.823	15.915	19.71
G1	17.37	12.099	11.770	8.198	30.35
G2	16.5	11.603	10.575	7.437	29.68
G3	15.35	10.778	9.281	6.516	29.79
G4	14.86	10.821	8.443	6.148	27.18
G5	13.64	9.825	7.351	5.295	27.97
G6	12.22	8.978	5.983	4.396	26.53
G7	11.83	9.700	5.085	4.170	18.00
G8	8.9	7.113	3.271	2.614	20.07

I B: Cylinders Settling In Vertical Orientation In Non-Newtonian Media

Units : Velocity, m/s

Test Fluid 1 : Glucose 87.5% Solution; $\mu = 1.28$ Pa.s; $\rho_f = 1375\ kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	1.31	1.214	0.084	0.078	7.29
A2	0.916	0.886	0.043	0.042	3.29
A3	0.72	0.724	0.027	0.027	-0.54
A5	6.43	5.123	0.814	0.861	20.32
A6	4.52	6.158	0.423	0.763	-36.24
A7	3.1	4.020	0.230	0.396	-29.69
A9	9.3	7.771	1.563	1.306	16.44
A10	7.26	7.426	0.900	0.921	-2.29
A11	4.55	4.686	0.448	0.462	-2.98
A13	16.56	15.469	3.507	3.276	6.59
A14	11.34	11.645	1.769	1.817	-2.69
A15	7.32	7.554	0.906	0.935	-3.20

Test Fluid 2 : Glucose 75% Solution; $\mu = 0.54$ Pa.s; $\rho_f = 1230\ kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	4.613	4.468	0.628	0.609	3.14
A2	3.05	3.353	0.306	0.337	-9.93

A3	2.2	2.580	0.176	0.207	-17.28
A4	1.1	1.177	0.070	0.075	-6.97
PC9	5.61	5.184	1.999	1.848	7.59
PC10	3.3	3.210	0.867	0.844	2.72
PC11	1.74	1.573	0.363	0.329	9.59
PC12	0.73	0.554	0.122	0.092	24.13
PC13	8.07	7.433	3.624	3.338	7.89
PC14	4.5	4.069	1.489	1.346	9.58
PC15	2.52	2.159	0.661	0.567	14.31
G1	9.13	8.009	2.170	1.904	12.28
G2	7.34	5.999	1.650	1.349	18.27
G3	6.4	5.170	1.357	1.096	19.22
G4	5.11	3.915	1.018	0.780	23.38
G5	4.45	3.372	0.841	0.638	24.22
G6	3.87	3.035	0.665	0.521	21.57
G7	2.452	1.801	0.370	0.272	26.57
G8	2.114	1.683	0.273	0.217	20.40
G9	13.2	11.587	3.938	3.456	12.22
G10	12.31	11.119	3.438	3.105	9.67
G11	10.03	8.573	2.612	2.233	14.53
G12	8.95	8.013	2.088	1.869	10.47
G13	7.15	5.886	1.594	1.313	17.68
G14	6.06	4.902	1.256	1.016	19.11
G15	4.72	3.694	0.888	0.695	21.74

Test Fluid 3 : Glucose 72% Solution; $\mu = 0.4$ Pa.s; $\rho_f = 1100\ kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	5.31	4.718	0.873	0.772	11.16
A2	2.96	2.767	0.359	0.334	6.53
A3	1.82	1.680	0.176	0.162	7.72
A5	14.38	11.036	4.662	3.560	23.26
A6	12.34	11.797	2.956	2.812	4.40
A7	7.5	6.853	1.423	1.294	8.63
PC9	7.6	6.628	3.270	2.838	12.79
PC10	5.07	4.833	1.609	1.526	4.67
PC11	3.06	2.849	0.772	0.715	6.89
PC12	2.12	2.088	0.426	0.418	1.52
PC13	10.5	9.133	3.974	4.928	13.02
PC14	7.05	6.450	2.346	2.564	8.51
PC15	4.68	4.303	1.296	1.356	8.05

Test Fluid 4: Glucose 50% Solution; $\mu = 0.204$ Pa.s; $\rho_f = 1050\ kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	10.3	7.228	3.170	2.161	29.83
A2	6.7	5.630	1.521	1.241	15.97
A3	5.017	4.684	0.909	0.824	6.64
A4	2.3	1.841	0.330	0.257	19.95

A14	38.11	35.543	35.945	33.523	6.74
A15	24.7	18.629	18.477	13.936	24.58
G1	25.5	25.680	17.279	17.401	-0.70
G2	20.25	17.039	12.978	10.920	15.86
G3	17.4	13.530	10.520	8.180	22.24
G4	14.1	9.867	8.011	5.607	30.02
G5	13.05	9.105	7.033	4.907	30.23
G6	12.17	8.917	5.959	4.366	26.73
G7	8.82	6.001	3.791	2.580	31.96
G8	6.94	4.800	2.551	1.764	30.84
G9	32.2	32.220	27.383	27.400	-0.06
G10	26.1	22.110	20.778	17.602	15.29
G11	24.33	20.446	18.066	15.181	15.97
G12	22.32	19.218	14.839	12.779	13.89
G13	19.85	16.162	12.619	10.275	18.58
G14	14.66	10.157	8.663	6.002	30.71
G15	12.72	8.781	6.823	4.710	30.97

I C: Cylinders Settling In Horizontal Orientation In Non-Newtonian Media.

Units Of Velocity: m/s

Notations: $V_t(H)$: Velocity predicted by Hartman et al. (1994).

Re(H): Reynolds number predicted by Hartman et al.(1994).

Test Fluid 1: CMC 1.5% Solution; n=0.546; k=1.218 $Pa.s^n$; $\rho_f = 1100 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	4.225	5.640	0.805	1.222	-33.50
A2	2.985	4.737	0.412	0.804	-58.69
A5	8.349	10.576	2.167	3.048	-26.68
A6	4.12	6.279	0.658	1.211	-52.39
G1	4.19	3.028	0.597	0.524	27.74
G2	3.71	2.787	0.483	0.448	24.87
G3	3.1	2.453	0.358	0.358	20.89
G4	2.64	2.235	0.267	0.295	15.32
G5	2.2	1.959	0.200	0.237	10.96
G6	1.71	1.645	0.133	0.177	3.79
G7	1.37	1.431	0.091	0.137	-4.45
G8	0.896	1.063	0.046	0.084	-18.68
G9	7.1	5.001	1.285	1.086	29.56
G10	5.92	4.280	0.952	0.836	27.70
G11	5.24	3.910	0.768	0.705	25.37
G12	4.11	3.264	0.508	0.511	20.58
G13	2.85	2.423	0.291	0.323	15.00

G14	2.092	1.933	0.178	0.224	7.59
G15	1.6	1.618	0.115	0.164	-1.15

Test Fluid 2: CMC 1.35% Solution; n= 0.634; k= 0.628 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	1.29	1.834	0.163	0.265	-42.14
A2	1.014	1.674	0.097	0.192	-65.04
A3	0.604	1.113	0.041	0.096	-84.29
P13	0.947	1.142	0.173	0.305	-20.61
P14	0.813	1.140	0.116	0.249	-40.17
P15	0.602	0.947	0.066	0.167	-57.34
PC5	1.03	1.275	0.140	0.253	-23.79
PC6	0.713	1.029	0.070	0.155	-44.33
PC7	0.495	0.796	0.037	0.094	-60.74
PC9	1.81	1.865	0.362	0.508	-3.03
PC10	1.36	1.658	0.202	0.355	-21.93
PC11	0.968	1.332	0.110	0.228	-37.62
PC12	0.611	0.966	0.051	0.127	-58.07
PC13	2.517	2.270	0.657	0.570	9.81
PC14	2.13	2.272	0.431	0.631	-6.65
PC15	1.85	2.220	0.307	0.525	-19.98

Test Fluid 3:CMC 1.25% Solution; n= 0.654; k= 0.472 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	1.908	2.438	0.254	0.39	-21.74
A2	1.39	2.087	0.136	0.26	-33.41
A3	0.9324	1.568	0.0686	0.152	-40.53
A4	0.434	0.832	0.0211	0.055	-47.82
P1	0.1248	0.285	0.0065	0.0216	-56.24
P2	0.085	0.198	0.0032	0.0108	-56.97
P3	0.058	0.133	0.0016	0.0055	-56.36
P4	0.035	0.077	0.0007	0.0023	-54.73
P5	0.4854	0.815	0.0628	0.139	-40.46
P6	0.36	0.685	0.0345	0.090	-47.43
P7	0.254	0.528	0.0185	0.054	-51.88
P8	0.1521	0.350	0.0080	0.027	-56.52
P9	0.65	0.933	0.1120	0.200	-30.33
P10	0.5614	0.923	0.0753	0.161	-39.19
P11	0.417	0.760	0.0434	0.107	-45.15
P12	0.265	0.547	0.0203	0.0593	-51.59
P13	1.0163	1.260	0.2377	0.35	-19.33
P14	0.78	1.132	0.1363	0.25	-31.09
P15	0.603	0.979	0.0828	0.17	-38.40
PC1	0.294	0.549	0.0205	0.0522	-46.45
PC2	0.2251	0.455	0.0117	0.0332	-50.55

PC3	0.185	0.400	0.0078	0.0241	-53.70
PC4	0.162	0.397	0.0056	0.0205	-59.24
PC6	0.973	1.422	0.131	0.24	-31.59
PC7	0.6645	1.090	0.068	0.14	-39.06
PC8	0.4136	0.775	0.031	0.078	-46.60
PC9	2.21	2.321	0.581	0.681	-4.77
PC10	1.81	2.245	0.364	0.53	-19.36
PC11	1.26	1.766	0.192	0.33	-28.67
PC12	0.803	1.289	0.090	0.19	-37.69
PC13	3.36	3.111	1.189	1.18	8.02
PC14	2.83	3.097	0.773	0.96	-8.62
PC15	2.25	2.773	0.488	0.71	-18.86

Test Fluid 4: CMC 1 % Solution; n= 0.671; k= 0.257 $\mathrm{Pa.s^n}$; $\rho_f = 1000\mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P5	1.254	1.41	0.59	0.68	-12.12
P6	0.85	1.13	0.29	0.42	-33.26
P7	0.568	0.85	0.14	0.25	-50.51
P8	0.332	0.57	0.06	0.12	-72.12
P9	1.102	1.08	0.60	0.58	2.42
P10	0.91	1.05	0.38	0.46	-15.34
P11	0.756	0.98	0.25	0.36	-29.65
P12	0.68	1.00	0.19	0.31	-46.56

P13	2.3	1.98	1.85	1.53	13.78
P14	2.21	2.26	1.43	1.48	-2.39
P15	1.5	1.72	0.73	0.88	-14.79
PC1	0.73	0.94	0.18	0.25	-28.69
PC2	0.454	0.68	0.08	0.13	-49.61
PC3	0.271	0.44	0.03	0.07	-63.32
PC4	0.198	0.37	0.02	0.04	-84.88
PC5	3.011	2.63	1.88	1.57	12.55
PC6	2.56	2.65	1.24	1.29	-3.34
PC7	1.562	1.82	0.55	0.67	-16.29
PC8	0.978	1.29	0.25	0.36	-32.07
PC9	3.56	2.72	2.84	1.98	23.63
PC10	2.814	2.53	1.69	1.47	10.18
PC11	1.92	1.93	0.87	0.88	-0.64
PC12	1.133	1.29	0.37	0.44	-13.64
PC13	7.16	5.32	8.38	5.66	25.68
PC14	6	5.08	5.40	4.33	15.31
PC15	4.8	4.47	3.43	3.13	6.81

Test Fluid 5: CMC 0.8 % Solution; n= 0.66; k= 0.153 Pa.s^n; $\rho_f = 1000 \text{kg}/\text{m}^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P5	3.37	3.646	4.206	4.675	-8.20
P6	2.4	2.705	2.186	2.566	-12.73

P7	1.81	2.141	1.287	1.608	-18.08
P8	1.12	1.398	0.582	0.780	-24.48
P9	5.5	5.771	9.774	10.425	-4.94
P10	3.9	4.018	5.044	5.250	-3.03
P11	2.26	2.341	2.086	2.188	-3.61
P12	1.4	1.511	0.946	1.047	-7.91
P13	4.02	3.495	7.480	6.201	13.07
P14	3.05	2.729	4.223	3.639	10.51
P15	2.18	2.017	2.311	2.082	7.50
PC1	2.04	2.261	1.371	1.575	-10.86
PC2	1.43	1.735	0.697	0.903	-21.32
PC3	1.02	1.313	0.380	0.536	-29.27
PC4	0.32	0.458	0.070	0.112	-42.66
PC5	5.01	4.364	7.156	5.946	12.90
PC6	4.14	3.751	4.538	3.976	9.40
PC7	3.4	3.200	2.989	2.755	5.89
PC8	2.3	2.239	1.520	1.466	2.67
PC9	8.2	7.069	16.691	13.680	13.80
PC10	6.62	5.600	10.249	8.191	15.40
PC11	5.63	4.854	7.088	5.810	13.79
PC12	4.18	3.649	4.095	3.413	12.70
PC13	8.16	6.255	19.316	13.527	23.35
PC14	7.01	5.349	12.890	8.966	23.73
PC15	5.1	3.871	7.217	4.988	24.10

Test Fluid 6: Methocel 1.0% Solution; n= 0.71; k =0.893 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	1.48	2.109	0.129	0.204	-42.52
A2	1.22	2.008	0.081	0.154	-64.59
A3	2.3	3.559	0.485	0.792	-54.74
A4	1.37	2.439	0.200	0.392	-77.99
P13	2.055	2.680	0.459	0.647	-30.41
P14	1.714	2.660	0.293	0.516	-55.21
P15	0.714	1.222	0.080	0.160	-71.12
PC9	2.73	3.124	0.562	0.669	-14.44
PC10	1.82	2.468	0.268	0.398	-35.60
PC11	1.6	2.444	0.193	0.334	-52.76
PC12	1.07	1.848	0.098	0.198	-72.75
PC13	4.02	4.712	1.564	1.340	-17.21
PC14	3.1	4.310	0.899	0.961	-39.03
PC15	2.29	3.579	0.517	0.642	-56.30

Test Fluid 7: Methocel 0.85% Solution; n= 0.688; k =0.743 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P5	0.918	1.243	0.222	0.330	-35.35
P6	0.53	0.837	0.088	0.160	-58.00

P7	0.219	0.367	0.024	0.046	-67.44
P9	3	3.098	1.487	1.551	-3.28
P10	2.32	2.835	0.860	1.117	-22.21
P11	1.5	2.052	0.414	0.623	-36.80
P12	0.763	1.167	0.109	0.189	-52.89
P13	0.59	1.036	0.063	0.131	-75.56
P14	1.16	1.752	0.188	0.321	-51.04
P15	0.607	1.066	0.065	0.136	-75.69
PC1	2.75	2.858	0.928	0.975	-3.92
PC2	2.13	2.628	0.539	0.708	-23.37
PC5	4.255	3.882	1.996	1.771	8.76
PC6	3.61	3.905	1.303	1.443	-8.17
PC7	2.31	2.781	0.620	0.790	-20.40
PC8	1.5625	2.111	0.318	0.471	-35.09
PC9	6.56	5.570	4.122	3.330	-15.09
PC10	5.55	5.504	2.679	2.650	0.82

Test Fluid 8: Sodium CMC 1.0% Solution; n=0.796; k= 0.381 Pa.s^n; $\rho_f = 1000 \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P1	0.29	0.4007	0.0392	0.0579	-38.18
P2	0.19	0.2729	0.0185	0.0286	-43.64
P3	0.15	0.2255	0.0116	0.0190	-50.34
P4	0.08	0.1120	0.0045	0.0068	-39.94

P5	1.15	1.1894	0.3538	0.3684	-3.43
P6	0.7	0.8297	0.1530	0.1877	-18.52
P7	0.525	0.6866	0.0899	0.1241	-30.78
P8	0.35	0.5061	0.0459	0.0716	-44.59
P9	1.9	1.7150	0.8111	0.7170	9.74
P10	1.32	1.4069	0.4106	0.4433	-6.58
P11	0.94	1.1098	0.2272	0.2775	-18.06
P12	0.6	0.7822	0.1105	0.1520	-30.36
P13	3	2.4868	1.6898	1.3482	-17.11
P14	2	1.9364	0.8132	0.7821	-3.18
P15	1.4	1.5017	0.4401	0.4789	-7.27
PC1	0.84	0.9916	0.1973	0.2409	-18.04
PC2	0.42	0.5173	0.0481	0.0618	-23.16
PC3	0.31	0.4031	0.0279	0.0383	-30.03
PC4	0.215	0.3030	0.0149	0.0225	-40.91
PC5	1	1.1439	0.1741	0.2047	-14.39
PC6	1.9	1.8630	0.5088	0.4969	-1.95
PC7	1.1	1.1652	0.2189	0.2346	-5.93
PC8	0.75	0.8875	0.1149	0.1407	-18.33
PC9	4.23	3.1226	2.1255	1.4750	-26.18
PC10	2.8	2.4050	1.0151	0.8453	-14.11
PC11	2	1.9056	0.5638	0.5319	-4.72
PC12	1.2	1.2479	0.2545	0.2668	-3.99
PC13	7.72	5.6846	5.2716	3.6471	-26.36

PC14	5.1	4.1936	2.5092	1.9826	-17.77
PC15	3.5	3.1303	1.3261	1.1593	-10.56

Test Fluid 9: Sodium CMC 0.85% Solution; n=0.826; k= 0.132 Pa.s^n; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P1	0.624	0.743	0.284	0.359	-19.12
P2	0.38	0.535	0.123	0.189	-40.78
P3	0.28	0.438	0.072	0.124	-56.38
P4	0.09	0.155	0.016	0.027	-72.34
P5	2	1.820	1.620	1.580	-8.98
P6	1.52	1.461	1.102	1.125	-3.90
P7	1.1	1.103	0.710	0.742	-0.31
P8	0.71	0.733	0.416	0.428	-3.19
P9	3.2	2.338	4.285	3.122	-26.95
P10	2.42	2.043	2.400	2.118	-15.59
P11	2	1.884	1.587	1.625	-5.78
P12	1.255	1.317	0.762	0.870	-4.95
P13	4.85	3.363	8.450	5.892	-30.66
P14	3.64	2.825	4.687	3.794	-22.39
P15	3	2.572	3.084	2.857	-14.26
PC1	1.744	2.056	0.912	1.306	-17.89
PC2	0.95	0.995	0.362	0.425	-4.76
PC3	0.65	0.768	0.192	0.259	-18.10

PC4	0.4124	0.560	0.093	0.146	-35.83
PC5	4.8	3.479	4.526	3.674	-27.53
PC6	3.55	2.641	2.983	2.433	-25.62
PC7	2.8	2.147	2.126	1.766	-23.32
PC8	1.7	1.314	1.159	0.915	-22.70
PC9	6.18	3.645	9.276	5.571	-41.01
PC10	5.55	3.742	6.357	4.662	-32.58
PC11	4.14	3.044	3.727	3.035	-26.48
PC12	2.74	2.198	1.904	1.695	-19.79
PC13	9.75	5.738	19.174	11.819	-41.15
PC14	7.41	4.665	10.793	7.293	-37.05
PC15	5.36	3.610	6.094	4.443	-32.65

I D: Cylinders Settling In Vertical Orientation In Non-Newtonian Media

Units : Velocity, m/s

Notations: $V_t(H)$: Velocity predicted by Hartman et al. (1994).

Re(H): Reynolds number predicted by Hartman et al.(1994).

Test Fluid 1: CMC 1.5% Solution; n=0.546; k=1.218 $Pa.s^n$; $\rho_f = 1100 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	4.225	5.640	0.805	1.222	-33.50
A2	2.985	4.737	0.412	0.804	-58.69
A5	8.349	10.576	2.167	3.048	-26.68

A6	4.12	6.279	0.658	1.211	-52.39
G1	4.19	3.028	0.597	0.524	27.74
G2	3.71	2.787	0.483	0.448	24.87
G3	3.1	2.453	0.358	0.358	20.89
G4	2.64	2.235	0.267	0.295	15.32
G5	2.2	1.959	0.200	0.237	10.96
G6	1.71	1.645	0.133	0.177	3.79
G7	1.37	1.431	0.091	0.137	-4.45
G8	0.896	1.063	0.046	0.084	-18.68
G9	7.1	5.001	1.285	1.086	29.56
G10	5.92	4.280	0.952	0.836	27.70
G11	5.24	3.910	0.768	0.705	25.37
G12	4.11	3.264	0.508	0.511	20.58
G13	2.85	2.423	0.291	0.323	15.00
G14	2.092	1.933	0.178	0.224	7.59
G15	1.6	1.618	0.115	0.164	-1.15

Test Fluid 2: CMC 1.35% Solution; n= 0.634; k= 0.628 $\mathrm{Pa.s}^n$; $\rho_f = 1000\mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	4.81	5.822	1.101	1.404	-21.04
A2	1.624	2.398	0.207	0.350	-47.64
A3	0.78	1.259	0.069	0.134	-61.47

P9	1.13	1.655	0.251	0.432	-46.44
P10	0.673	1.177	0.102	0.224	-74.89
P13	2.83	3.545	1.017	1.402	-25.25
P14	1.075	1.640	0.223	0.407	-52.58
PC5	3.616	4.588	1.027	1.417	-26.88
PC6	1.03	1.614	0.152	0.285	-56.72
PC7	0.55	0.979	0.056	0.125	-78.09
PC9	3.5	3.870	1.175	1.356	-10.58
PC10	1.9	2.518	0.420	0.623	-32.52
PC11	1.012	1.538	0.154	0.276	-51.95
PC12	0.5715	1.002	0.061	0.134	-75.35
PC13	6.8	6.923	3.370	3.452	-1.81
PC14	3.43	4.004	1.090	1.352	-16.74
PC15	1.81	2.405	0.393	0.585	-32.85

Test Fluid 3: CMC 1.25% Solution; n= 0.654; k= 0.472 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
A1	5.19	6.36	0.979	1.411	-18.31
A2	1.83	2.71	0.197	0.368	-32.59
A3	1.03	1.73	0.0784	0.1728	-40.41
A4	0.43	0.83	0.0210	0.0553	-47.81
P1	0.19	0.46	0.0116	0.0408	-57.76
P2	0.10	0.24	0.00391	0.01392	-58.27

P3	0.06	0.15	0.00183	0.00633	-57.39
P4	0.03	0.06	0.00053	0.00147	-49.88
P5	0.64	1.06	0.0917	0.1972	-39.32
P6	0.49	0.93	0.0525	0.1360	-47.18
P7	0.27	0.57	0.0205	0.0604	-52.01
P8	0.11	0.25	0.00532	0.01701	-54.82
P9	1.23	1.68	0.26	0.44	-26.87
P10	0.87	1.41	0.14	0.29	-38.09
P11	0.48	0.87	0.05249	0.12910	-45.09
P12	0.22	0.45	0.01584	0.04572	-51.26
P13	3.62	4.28	1.314	1.809	-15.48
P14	1.22	1.74	0.249	0.439	-29.69
P15	1.04	1.66	0.173	0.355	-37.36
PC1	1.87	3.17	0.248	0.552	-40.94
PC2	1.27	2.56	0.121	0.339	-50.23
PC3	0.81	1.84	0.057	0.188	-55.81
PC4	0.08	0.18	0.00227	0.00699	-53.50
PC6	2.95	3.52	0.71	0.99	-16.06
PC7	1.76	2.51	0.29	0.51	-29.74
PC8	0.71	1.17	0.074	0.158	-38.98
PC9	6.38	6.75	2.42	2.87	-5.51
PC10	2.34	2.88	0.51	0.75	-18.64
PC11	1.33	1.87	0.208	0.358	-28.53
PC12	0.70	1.12	0.074	0.156	-38.01

PC13	7.93	7.77	3.78	4.03	2.01
PC14	4.38	4.84	1.39	1.74	-9.45
PC15	2.09	2.57	0.44	0.64	-18.71

Test Fluid 4: CMC 1 % Solution; n= 0.671; k= 0.257 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P5	1.878	2.093	1.003	1.159	-11.45
P6	0.992	1.317	0.350	0.511	-32.76
P7	0.561	0.845	0.141	0.242	-50.54
P8	0.213	0.364	0.033	0.068	-71.02
P9	3.36	3.335	2.626	2.604	0.73
P10	1.78	2.039	0.921	1.103	-14.54
P11	1.04	1.342	0.386	0.542	-29.08
P12	0.351	0.521	0.078	0.132	-48.54
P13	5	4.659	5.202	4.744	6.83
P14	4.082	4.354	3.236	3.530	-6.67
P15	1.41	1.618	0.675	0.810	-14.77
PC5	5.24	4.797	3.920	3.487	8.46
PC6	3.34	3.483	1.759	1.859	-4.28
PC7	1.84	2.139	0.681	0.831	-16.24
PC8	0.54	0.724	0.114	0.169	-34.07
PC9	10.9	10.155	12.543	11.431	6.84
PC10	7.5	7.382	6.222	6.094	1.58

PC11	1.85	1.862	0.830	0.837	-0.63
PC12	1.14	1.295	0.375	0.444	-13.62
PC13	14.84	13.736	22.074	19.956	7.44
PC14	10	9.273	10.642	9.636	7.27
PC15	4.44	4.110	3.097	2.796	7.43

Test Fluid 5 : CMC 0.8 % Solution; n= 0.66; k= 0.153 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P1	1.18	1.077	0.659	0.583	8.71
P2	0.473	0.605	0.158	0.220	-27.83
P3	0.417	0.661	0.115	0.213	-58.48
P4	0.17	0.346	0.030	0.077	-103.69
P5	4.98	3.372	7.098	4.210	32.28
P6	2.173	1.914	1.913	1.614	11.92
P7	1.011	1.124	0.588	0.678	-11.18
P8	0.65	0.917	0.280	0.444	-41.10
P9	8.5	5.165	17.514	8.984	39.24
P10	4.03	3.323	5.270	4.070	17.55
P11	2	1.932	1.771	1.691	3.39
P12	0.91	1.098	0.531	0.683	-20.66
P13	10.5	6.588	27.080	14.501	37.26
P14	5.815	4.357	10.027	6.810	25.08
P15	2.7	2.371	3.078	2.587	12.17

PC1	3.93	2.979	3.302	2.278	24.20
PC2	1.92	1.963	1.034	1.065	-2.22
PC3	1.48	1.781	0.629	0.806	-20.32
PC4	0.41	0.686	0.097	0.192	-67.23
PC5	13.31	8.403	26.501	14.309	36.87
PC6	6.079	4.445	7.594	4.992	26.88
PC7	3.01	2.641	2.539	2.130	12.26
PC8	1.22	1.332	0.650	0.731	-9.16
PC9	17	10.210	44.338	22.391	39.94
PC10	8.53	5.732	14.394	8.450	32.80
PC11	6.9	5.706	9.309	7.216	17.31
PC12	2.018	1.899	1.543	1.422	5.91

Test Fluid 6 : Methocel 0.85% Solution; n= 0.688; k =0.743 Pa.s^n; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P5	1.83	2.448	0.546	0.797	-33.74
P6	0.65	1.029	0.115	0.209	-58.34
P7	0.21	0.344	0.022	0.043	-66.39
P8	0.086	0.142	0.0060	0.011	-65.12
P9	2.71	3.148	1.109	1.347	-16.15
P10	1.20	1.641	0.311	0.467	-36.44
P11	0.41	0.623	0.066	0.112	-50.40
P12	0.3	0.511	0.037	0.074	-70.21

P13	4.08	4.333	2.220	2.401	-6.20
P14	1.75	2.120	0.595	0.765	-21.17
P15	0.61	0.822	0.128	0.189	-34.80
PC2	0.61	1.066	0.065	0.136	-75.69
PC4	0.22	0.373	0.012	0.025	-71.17
PC5	4.5	4.800	1.763	1.917	-6.67
PC6	2.05	2.528	0.512	0.673	-23.29
PC7	0.80	1.106	0.128	0.195	-37.71
PC8	0.63	0.989	0.080	0.143	-56.95
PC9	7.08	6.890	3.875	3.740	2.68
PC10	3.45	3.722	1.228	1.356	-7.89
PC11	1.05	1.247	0.222	0.278	-18.73
PC12	0.84	1.133	0.142	0.209	-34.90
PC13	11.2	10.713	8.275	7.809	-4.35
PC14	5.42	5.361	2.597	2.561	-1.08
PC15	2.04	2.167	0.619	0.669	-6.21

Test Fluid 7 : Sodium CMC 1.0% Solution; n=0.796; k= 0.381 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P1	0.36	0.473	0.0502	0.0707	-32.77
P2	0.2	0.269	0.0197	0.0282	-34.60
P3	0.13	0.163	0.0093	0.0129	-30.59
P4	0.082	0.084	0.0047	0.0048	-2.33

P5	1.73	2.191	0.48	0.64	-26.50
P6	0.802	0.939	0.18	0.22	-17.14
P7	0.46	0.510	0.09	0.0987	-10.21
P8	0.31	0.321	0.05	0.0553	-3.53
P9	3.6	3.695	1.75	1.81	-2.64
P10	1.54	1.664	0.49	0.54	-8.05
P11	0.51	0.528	0.11	0.11	-3.48
P12	0.22	0.219	0.033	0.033	0.65
P13	4.44	4.097	2.71	2.46	-7.72
P14	2.01	1.950	0.82	0.79	-3.01
P15	1.01	1.017	0.297	0.30	-0.67
PC1	0.402	0.402	0.081	0.0812	0.03
PC2	0.58	0.720	0.071	0.0920	-24.07
PC3	0.35	0.442	0.032	0.0428	-26.41
PC4	0.17	0.198	0.011	0.0135	-17.90
PC5	3.75	3.887	1.23	1.28	-3.66
PC6	2	1.961	0.54	0.53	-1.95
PC7	1.21	1.143	0.28	0.26	-5.53
PC8	0.71	0.626	0.14	0.12	-11.99
PC9	7.78	6.796	4.43	3.76	-12.65
PC10	3.7	3.351	1.42	1.26	-9.44
PC11	1.41	1.259	0.37	0.32	-10.74
PC12	1.02	1.007	0.21	0.21	-1.24
PC13	16.1	15.568	12.77	12.26	-3.30

PC14	6.71	5.944	3.49	3.02	-11.42
PC15	2.56	2.171	0.91	0.75	-15.19

Test Fluid 8 : Sodium CMC 0.85% Solution; n=0.826; k= $0.132\,Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	$V_t(H) \times 10^2$	Re	Re(H)	Deviation
P1	0.91	1.056	0.442	0.567	-16.03
P2	0.48	0.669	0.162	0.253	-39.43
P3	0.27	0.422	0.069	0.119	-56.44
P4	0.18	0.322	0.035	0.071	-78.63
P5	3.05	2.541	3.205	2.858	-16.68
P6	1.72	1.656	1.278	1.325	-3.94
P7	1.03	1.113	0.573	0.671	-8.62
P8	0.65	0.805	0.277	0.375	-23.82
P9	5.7	4.558	8.436	7.453	-20.03
P10	3	2.560	3.089	2.843	-14.66
P11	1.4	1.317	1.044	1.019	-5.91
P12	1	1.057	0.583	0.653	-5.65
P13	6.06	4.406	10.974	8.378	-27.29
P14	4.25	3.353	5.621	4.743	-21.11
P15	2.08	1.757	2.007	1.738	-15.55
PC1	1.14	1.078	0.816	0.781	-5.43
PC2	0.95	0.995	0.362	0.425	-4.76
PC3	0.65	0.768	0.192	0.259	-18.10

PC4	0.41	0.560	0.093	0.146	-35.83
PC5	1.52	1.333	0.808	0.768	-12.33
PC6	4	2.996	3.431	2.868	-25.10
PC7	2.52	2.084	1.645	1.519	-17.30
PC8	1.28	1.192	0.614	0.625	-6.89
PC9	9.52	6.202	15.401	11.134	-34.85
PC10	6.72	4.648	7.957	6.183	-30.84
PC11	4.23	3.115	3.823	3.127	-26.37
PC12	2.7	2.165	1.871	1.662	-19.81
PC13	16	11.277	34.289	28.508	-29.52
PC14	9.88	6.577	15.121	11.412	-33.40
PC15	5.7	3.864	6.550	4.855	-32.21

DRAG COEFFICIENTS – REYNOLDS NUMBER DATA

APPENDIX II A: Spheres Settling In Newtonian Media

Units : Velocity, m/s

Test Fluid 1: Glycerine ; μ=0.267 Pa.s; ρ_f = 1236.7 kg/m^3

Particle ID	$V_t \times 10^2$	Re	C_D
T1	5.4	1.534	18.218
T2	8.12	3.075	10.743
T3	10.94	5.178	7.398
S1	29.5	8.280	4.622
S2	37.8	14.062	3.731
GS1	19.3	11.190	4.286
GS2	24.93	17.109	3.040
GS3	34.7	30.334	1.999
GS4	38.6	37.635	1.802

Test Fluid 2: Silicon Oil; μ=0.323 Pa.s; ρ_f =.1046.8 kg/m^3

Particle ID	$V_t \times 10^2$	Re	C_D
T1	7.65	2.172	9.077
T2	9.7	3.673	7.528
T3	11.62	5.500	6.557
S1	28.63	8.036	4.907
S2	36.78	13.683	3.941

GS1	17.1	6.912	5.459
GS2	20.2	9.665	4.631
GS3	31.7	19.320	2.395
GS4	34.96	23.764	2.196

II B: Cylinders Settling In Horizontal Orientation In Newtonian Med

Units : Velocity, m/s

Test Fluid 1: Glycerine ; μ=0.267 Pa.s; ρ_f = 1236.7 kg/m^3

Particle ID	$V_t \times 10^2$	Re	C_D
A1	8.31	2.352	13.866
A2	5.82	1.215	20.847
A3	3.92	0.653	36.680
A4	2.52	0.333	70.350
P9	4.94	2.545	10.862
P10	3.86	1.752	13.122
P11	2.81	1.066	19.675
P12	2.42	0.694	21.147
PC1	1.23	0.244	66.964
PC2	0.85	0.148	103.408
PC3	0.69	0.100	125.985
PC4	0.32	0.034	476.362
PC5	1.6	0.622	78.024

PC6	1.13	0.387	115.575
PC7	0.83	0.237	169.686
PC8	0.78	0.168	151.817

Test Fluid 2: Silicon Oil; μ=0.323 Pa.s; $\rho_f = 1046.8\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	6.83	1.324	28.241
A2	6.02	0.860	26.808
A3	4.32	0.493	41.552
A4	3.17	0.287	61.166
P1	1.28	0.248	173.446
P2	0.88	0.126	269.392
P3	0.78	0.089	272.837
P4	0.69	0.062	280.099
P5	4.62	1.766	26.226
P6	3.43	0.969	35.104
P7	2.23	0.499	65.936
P8	1.48	0.263	118.889
P9	9.10	4.965	8.982
P10	8.14	3.746	8.276
P11	7.28	2.926	8.222
P12	6.99	2.553	7.118
PC1	2.88	0.664	40.756
PC2	1.32	0.226	144.330

PC3	0.91	0.136	262.245
PC4	0.41	0.045	939.252

Test Fluid 3: Glucose 92.5% Solution; $\mu = 10.7 \text{Pa.s}$; $\rho_f = 1590 \text{kg/m}^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	0.17	0.00149	21272.32
A2	0.098	0.00064	46101.89
A3	0.077	0.00040	59777.15
A4	0.045	0.00019	139566.3
A5	0.63	0.0111	2436.58
A6	0.36	0.0032	1269.53
A7	0.26	0.0023	915.26
A8	0.14	0.0013	806.40
A9	0.83	0.0193	2280.23
A10	0.66	0.0113	2659.81
A11	0.473	0.0064	4115.09
A12	0.311	0.0034	7588.027
A13	1.49	0.0437	891.66
A14	1.04	0.0224	1348.29
A15	0.79	0.0135	1851.83
S1	0.99	0.0104	3142.78
S2	0.78	0.0061	3690.13
S3	0.64	0.0044	4381.26

S4	0.31	0.0016	14553.86
S5	0.60	0.0105	16902.36
S6	0.56	0.0073	14174.08
S7	0.50	0.0051	14096.99
S8	0.328	0.0027	26131.19
S9	5.0	0.116	325.21
S10	3.48	0.0597	488.85
S11	2.46	0.0335	778.63
S12	1.62	0.018	1428.94
S13	6.81	0.170	3142.78
S14	4.84	0.104	3690.13
S15	3.97	0.0680	4381.26

Test Fluid 4 : Glucose 87.5% Solution; $\mu = 1.28$ Pa.s; $\rho_f = 1375\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	0.91	0.058	985.931
A2	0.74	0.035	1099.521
A3	0.61	0.023	1278.939
A5	5.14	0.651	60.928
A6	4.03	0.377	73.084
A7	3.14	0.233	95.547
A9	7.03	1.182	43.187
A10	6.4	0.793	38.466
A11	4.1	0.404	74.478

A13	11.4	2.415	20.714
A14	9.5	1.482	21.973
A15	7.62	0.943	27.088
PC9	1.65	0.262	135.745
PC10	1.24	0.145	177.277
PC11	1.04	0.097	200.259
PC12	0.54	0.040	592.135
PC13	2.88	0.577	56.149
PC14	2.12	0.313	76.337
PC15	1.53	0.179	115.786

Test Fluid 5 : Glucose 80% Solution; $\mu = 0.652$ Pa.s; $\rho_f = 1270\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	2.14	0.249	207.126
A2	1.84	0.158	206.616
A3	1.26	0.086	351.692
A5	6.39	1.467	45.801
A6	4.42	0.750	70.727
A7	3.84	0.516	74.225
A9	13.15	4.008	14.352
A10	10.16	2.284	17.733
A11	7.5	1.340	25.859
A13	16.5	6.337	11.488

A14	12.17	3.444	15.546
A15	9.34	2.096	20.947
PC9	1.23	0.375	281.968
PC10	1.07	0.241	274.818
PC11	0.53	0.095	890.071
PC12	0.28	0.040	2471.085
PC13	2.01	0.772	133.063
PC14	1.23	0.348	261.766
PC15	0.46	0.103	1484.376
G1	4.08	0.829	82.168
G2	3.3	0.634	118.801
G3	2.63	0.477	176.447
G4	1.8	0.307	353.992
G5	0.89	0.144	1373.500

Test Fluid 6 : Glucose 72% Solution; $\mu = 0.54$ Pa.s; $\rho_f = 1230\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	3.14	0.428	101.912
A2	2.54	0.255	114.856
A3	2.1	0.168	134.118
A4	1.03	0.065	441.889
PC9	3.75	1.336	36.050
PC10	2.34	0.615	68.286

PC11	1.72	0.359	100.783
PC12	0.74	0.123	434.875
PC13	4.85	2.178	27.159
PC14	3.2	1.059	45.960
PC15	2.15	0.564	80.749
G1	9.13	2.170	17.475
G2	7.34	1.650	25.573
G3	6.4	1.357	31.732
G4	5.11	1.018	46.776
G5	4.45	0.841	58.508
G6	3.87	0.665	70.276
G7	2.45	0.370	153.699
G8	2.11	0.273	176.792
G9	9.32	2.780	21.046
G10	8.55	2.388	23.411
G11	7.58	1.974	27.781
G12	6.62	1.544	32.617
G13	5.86	1.307	39.796
G14	4.72	0.978	57.018
G15	4.38	0.824	60.102

Test Fluid 7: Glucose 50% Solution; $\mu = 0.204$ Pa.s; $\rho_f = 1050\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	7.5	2.308	25.167
A2	6.15	1.396	27.602
A3	3.84	0.696	56.511
A4	2.35	0.337	119.597
A9	24.5	19.730	6.171
A10	20.5	12.176	6.501
A11	16.5	7.788	7.974
A13	34.5	35.012	3.922
A14	28.31	21.165	4.290
A15	23.5	13.934	4.938
PC9	11.2	9.019	8.719
PC10	9.62	5.714	8.717
PC11	7.41	3.497	11.675
PC12	5.4	2.032	17.525
PC13	14.82	15.040	6.276
PC14	11.4	8.523	7.813
PC15	7.85	4.655	13.069
G1	16.7	8.969	7.549
G2	15.5	7.874	8.288
G3	14.85	7.117	8.518
G4	13.6	6.125	9.544
G5	12.16	5.195	11.325

G6	11.8	4.579	10.925
G7	10.43	3.554	12.277
G8	9.19	2.677	13.521
G9	19.62	13.225	6.864
G10	17.55	11.075	8.031
G11	16.8	9.888	8.174
G12	15.82	8.338	8.255
G13	14.6	7.357	9.266
G14	13.72	6.426	9.753
G15	11.68	4.966	12.215

Test Fluid 8: Glucose 40% Solution; $\mu = 0.154$ Pa.s; $\rho_f = 1000\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	12.35	4.796	9.282
A2	9.5	2.720	11.568
A3	7.34	1.678	15.467
A4	3.5	0.634	53.916
A9	24.5	24.891	6.171
A10	21.5	16.111	5.910
A11	17.5	10.420	7.088
A13	35.5	45.452	3.704
A14	29.31	27.645	4.003
A15	26.5	19.823	3.883
PC9	12.2	12.395	7.349

PC10	10.12	7.583	7.877
PC11	8.41	5.008	9.063
PC12	5.84	2.772	14.983
PC13	17.82	22.815	4.341
PC14	14.4	13.582	4.897
PC15	11.85	8.864	5.735
G1	17.37	11.770	6.978
G2	16.5	10.575	7.314
G3	15.35	9.281	7.972
G4	14.86	8.443	7.994
G5	13.64	7.351	9.000
G6	12.22	5.983	10.187
G7	11.83	5.085	9.543
G8	8.9	3.271	14.416
G9	21.2	18.028	5.879
G10	19.55	15.564	6.472
G11	18.8	13.960	6.527
G12	17.2	11.437	6.983
G13	16.56	10.527	7.202
G14	12.72	7.516	11.347
G15	10.68	5.728	14.610
S5	59.39	31.699	2.984
S6	54.42	25.583	2.626
S7	38.84	15.208	4.084

S13	112.3	143.780	1.396
S14	68.11	64.240	2.795
S15	53.7	40.170	3.567

II C: Cylinders Settling In Vertical Orientation In Newtonian Media

Units : Velocity, m/s

Test Fluid 1: Glycerine; μ=0.267 Pa.s; $\rho_f = 1236.7\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	12.2	2.420	6.433
A2	6.44	1.122	17.026
A3	4.31	0.627	30.342
A4	2.12	0.232	99.401
P9	7.4	3.813	4.841
P10	5.46	2.479	6.558
P11	4.11	1.558	9.197
P12	3.7	1.061	9.046
PC1	2.69	2.072	14.001
PC2	1.31	0.811	43.536
PC3	0.82	0.416	88.258
PC4	0.55	0.215	155.124
PC5	3.91	1.521	13.065
PC6	2.8	0.959	18.824
PC7	1.23	0.351	77.267

PC8	0.482	0.103	399.613

Test Fluid 2: Silicon Oil; μ=0.323 Pa.s; $\rho_f = 1046.8\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	18.2	3.527	76.318
A2	9.29	1.328	140.236
A3	6.16	0.703	150.903
A4	2.02	0.183	83.057
P1	1.3	0.300	3163.714
P2	0.79	0.135	11421.459
P3	0.42	0.062	42852.908
P4	0.28	0.030	143042.365
P5	5.86	2.239	111.751
P6	3.76	1.063	366.602
P7	2.64	0.590	940.816
P8	1.89	0.336	2311.306
PC1	2.88	0.664	40.756
PC2	1.319	0.226	144.330
PC3	0.912	0.136	262.245
PC4	0.412	0.045	939.252

Test Fluid 3: Glucose 92.5% Solution; $\mu = 10.7 Pa.s$; $\rho_f = 1590 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	0.19	0.00204	16071.618
A2	0.10	0.00078	44498.466
A3	0.087	0.00059	47015.031
A4	0.049	0.00024	116952.238
A5	0.62	0.0108	3129.650
A6	0.41	0.00535	5127.435
A7	0.28	0.00289	8729.868
A8	0.15	0.00121	25118.251
A9	1.96	0.0456	408.906
A10	1.12	0.0192	923.638
A11	0.88	0.0120	1186.178
A12	0.52	0.0057	2703.798
A13	1.69	0.0495	693.106
A14	1.15	0.0248	1102.688
A15	0.781	0.0134	1896.194
S1	1.52	0.0161	1327.823
S2	0.89	0.00699	2856.175
S3	0.67	0.00454	4083.435
S4	0.28	0.00140	18049.499
S5	0.69	0.01212	12630.713

S6	0.51	0.00663	17047.250
S7	0.48	0.00487	15688.742
S8	0.45	0.00367	13821.453

Test Fluid 4 : Glucose 87.5% Solution; $\mu = 1.28$ Pa.s; $\rho_f = 1375\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	1.31	0.084	475.759
A2	0.916	0.043	717.589
A3	0.72	0.027	927.056
A5	6.43	0.814	38.933
A6	4.52	0.423	58.213
A7	3.1	0.230	98.029
A9	9.3	1.563	24.698
A10	7.26	0.900	29.892
A11	4.55	0.448	60.475
A13	16.56	3.507	9.816
A14	11.34	1.769	15.421
A15	7.32	0.906	29.353
PC9	1.91	0.304	101.304
PC10	1.47	0.172	126.142
PC11	0.85	0.079	299.793
PC12	0.42	0.031	978.832
PC13	3.14	0.629	47.236
PC14	2.62	0.387	49.981

PC15	1.75	0.205	88.852

Test Fluid 5 : Glucose 80% Solution; $\mu = 0.652$ Pa.s; $\rho_f = 1270\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	4.31	0.502	51.063
A2	2.6	0.223	103.479
A3	1.7	0.117	193.199
A5	10.3	2.365	17.628
A6	5.85	0.993	40.375
A7	3.86	0.519	73.457
A9	14.8	4.510	11.330
A10	11.2	2.518	14.593
A11	7.75	1.384	24.217
A13	19.5	7.489	8.225
A14	13.4	3.791	12.831
A15	9	2.020	22.559
PC9	2.4	0.731	74.061
PC10	1.34	0.301	175.228
PC11	1.06	0.189	222.518
PC12	0.68	0.097	431.029
PC13	2.42	0.929	91.795
PC14	1.34	0.379	220.553
PC15	0.54	0.121	1077.139
G1	6.8	1.382	29.580

G2	5.4	1.038	44.367
G3	2.85	0.517	150.258
G4	1.84	0.314	338.768
G5	0.85	0.137	1505.812

Test Fluid 6 : Glucose 72% Solution; $\mu = 0.54$ Pa.s; $\rho_f = 1230\ \mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	4.61	0.628	47.219
A2	3.05	0.306	79.657
A3	2.2	0.176	122.203
A4	1.1	0.070	387.438
PC9	5.61	1.999	16.108
PC10	3.3	0.867	34.335
PC11	1.74	0.363	98.136
PC12	0.73	0.122	444.458
PC13	8.07	3.624	9.810
PC14	4.5	1.489	23.241
PC15	2.52	0.661	58.777
G1	9.13	2.170	17.475
G2	7.34	1.650	25.573
G3	6.4	1.357	31.732
G4	5.11	1.018	46.776
G5	4.45	0.841	58.508
G6	3.87	0.665	70.276

G7	2.45	0.370	153.699
G8	2.11	0.273	176.792
G9	13.2	3.938	10.492
G10	12.31	3.438	11.294
G11	10.03	2.612	15.867
G12	8.95	2.088	17.845
G13	7.15	1.594	26.732
G14	6.06	1.256	34.590
G15	4.72	0.888	51.755

Test Fluid 7: Glucose 50% Solution; $\mu = 0.204$ Pa.s; $\rho_f = 1050\ \mathrm{kg/m^3}$

Particle ID	$V_t\times10^2$	Re	C_D
A1	10.3	3.170	13.344
A2	6.7	1.521	23.256
A3	5.02	0.909	33.106
A4	2.3	0.330	124.853
A9	33.75	27.179	3.252
A10	26.4	15.681	3.920
A11	16.83	7.944	7.664
A13	42.3	42.928	2.609
A14	34.18	25.553	2.943
A15	24.7	14.646	4.470
PC9	14.3	11.516	5.349

PC10	12.3	7.306	5.332
PC11	9.34	4.408	7.348
PC12	4.43	1.667	26.039
PC13	18.7	18.978	3.942
PC14	12.15	9.083	6.878
PC15	6.82	4.044	17.314
G1	20.5	11.010	5.010
G2	18.5	9.398	5.818
G3	17.04	8.166	6.469
G4	16.51	7.436	6.476
G5	15.85	6.771	6.665
G6	14.17	5.499	7.576
G7	12.52	4.266	8.520
G8	9.104	2.652	13.777
G9	26.2	17.660	3.849
G10	22.1	13.946	5.064
G11	18.33	10.788	6.866
G12	14.15	7.458	10.318
G13	11.5	5.795	14.935
G14	9.66	4.525	19.674
G15	6.72	2.857	36.902

Test Fluid 8: Glucose 40% Solution; $\mu = 0.154$ Pa.s; $\rho_f = 1000\ \text{kg/m}^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	15.6	6.058	5.817
A2	11.5	3.293	7.894
A3	6.7	1.531	18.563
A4	3.3	0.598	60.650
A9	40.15	40.791	2.298
A10	30.24	22.660	2.987
A11	21.83	12.999	4.555
A13	42.3	54.158	2.609
A14	38.11	35.945	2.367
A15	24.7	18.477	4.470
PC9	20.3	20.624	2.654
PC10	13.83	10.364	4.218
PC11	8.34	4.966	9.216
PC12	5.43	2.577	17.332
PC13	24.7	31.624	2.259

II D. Cylinders settling In Horizontal Orientation In Non-Newtonian Media

Units : Velocity, m/s

Test Fluid1: CMC 2.5% Solution; n=.465; k=8.07 $Pa.s^n$; $\rho_f = 1156 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	0.045	9.54E-05	552668.6
A2	0.03	4.44E-05	917032.5
A3	0.024	2.84E-05	1143691
A4	0.012	8.78E-06	3626021
A5	0.2011	0.00131	54560.49
A6	0.135	0.00062	89451.8
A7	0.0842	0.00027	182143.4
A8	0.057	0.00013	315659.9
A9	0.532	0.00666	10345.91
A10	0.42	0.00402	12243.23
A11	0.312	0.00229	17629.86
A12	0.14	0.00060	69799.12
A13	1.03	0.02048	3478.204
A14	0.704	0.00990	5484.783
A15	0.521	0.00560	7942.654
S1	0.73	0.00696	480.7305
S2	0.61	0.00459	507.721
S3	0.37	0.00191	1101.502
S4	0.204	0.00069	2872.037

PC5	0.0375	9.85E-05	359167.9
PC6	0.028	5.47E-05	475990.3
PC7	0.02	2.93E-05	738984.4
PC8	0.0089	7.57E-06	2963785
PC9	0.07	0.000293	136789.7
PC10	0.0471	0.000139	222848.7
PC11	0.0381	8.99E-05	270623.5
PC12	0.026	4.5E-05	463251.5
PC13	0.091	0.000489	102001
PC14	0.068	0.000271	134568.8
PC15	0.028	6.22E-05	629481

Test Fluid 2: CMC 1.5% Solution; n=0.546; k=1.218 $Pa.s^n$; $\rho_f = 1100 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	0.704	0.0410	2453.328
A2	0.475	0.0196	3974.213
A3	0.3944	0.0132	4601.174
A4	0.23	0.0053	10723.790
A5	4.225	0.8049	134.295
A6	2.985	0.4117	198.783
A7	2.1	0.2174	318.134
A8	1.17	0.0819	813.970
P9	0.435	0.0345	2160.825

P10	0.301	0.0171	3328.646
P11	0.212	0.0091	5332.028
P12	0.132	0.0040	10963.881
P13	0.529	0.0520	1841.299
P14	0.447	0.0344	1899.748
P15	0.335	0.0199	2682.611
PC1	0.165	0.0050	11349.969
PC2	0.107	0.0022	19903.636
PC3	0.076	0.0012	31490.305
PC4	0.0431	0.0005	77608.814
PC5	0.56	0.0426	1942.670
PC6	0.435	0.0250	2378.761
PC7	0.283	0.0118	4451.820
PC8	0.21	0.0067	6421.010
PC9	1.13	0.1381	633.152
PC10	0.896	0.0834	742.765
PC11	0.657	0.0469	1097.741
PC12	0.395	0.0198	2420.943
PC13	2.08	0.3804	235.492
PC14	1.68	0.2360	265.925
PC15	1.22	0.1306	399.939

Test Fluid 3: CMC 1.35% Solution; n= 0.634; k= 0.628 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	1.29	0.163	850.69
A2	1.014	0.097	1015.35
A3	0.604	0.041	2284.13
A4	0.38	0.019	4573.92
A5	0.0974	0.0036	16473.2
A6	0.0696	0.0019	23791.12
A7	0.042	0.0008	52148.15
A8	0.0273	0.0004	97830.37
P1	0.0974	0.0036	16473.2
P2	0.0696	0.0019	23791.12
P3	0.042	0.0008	52148.15
P4	0.0273	0.0004	97830.37
P5	0.365	0.0339	2312.72
P6	0.246	0.0163	3761.77
P7	0.17	0.0085	6239.45
P8	0.103	0.0037	13498.98
P9	0.702	0.0992	829.71
P10	0.475	0.0480	1336.64
P11	0.341	0.0264	2060.89
P12	0.2	0.0110	4775.87
P13	0.947	0.173	574.56

P14	0.813	0.116	574.29
P15	0.602	0.0662	830.72
PC1	0.217	0.0108	8877.70
PC2	0.147	0.0053	14266.67
PC3	0.117	0.0033	17975.85
PC4	0.06	0.0012	54177.67
PC5	1.03	0.14	776.89
PC6	0.713	0.070	1197.86
PC7	0.495	0.037	1968.60
PC8	0.303	0.016	4172.67
PC9	1.81	0.362	333.86
PC10	1.36	0.202	436.16
PC11	0.968	0.110	684.13
PC12	0.611	0.051	1368.84
PC13	2.517	0.657	217.57
PC14	2.13	0.431	223.81
PC15	1.85	0.307	235.30

Test Fluid 4: CMC 1.27% Solution; n= 0.785; k= 0.221 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A5	9.5	7.954	30.926
A6	3.57	1.905	162.256
A7	2.22	0.892	331.432

A8	0.61	0.156	3450.066
A9	15.7	18.295	15.026
A10	7.7	6.058	46.076
A11	4.21	2.427	122.477
A13	20.35	30.073	11.271
A14	12.3	12.826	22.728
A15	6.9	5.294	57.280
A16	64.16	225.406	2.492
A17	57.32	179.266	2.777
A18	44.8	117.797	3.900
A19	35.2	73.284	5.014
S5	27.5	28.963	13.919
S6	18.6	14.196	22.479
S7	11.62	6.672	45.623
S9	49.4	59.041	4.313
S10	24.23	19.579	13.247
S11	22.1	14.579	12.613
S13	47.7	84.722	7.737
BS1	100.95	257.662	2.332

Test Fluid 5:CMC 1.25% Solution; n= 0.654; k= 0.472 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	1.908	0.362	388.862

A2	1.39	0.194	540.331
A3	0.932	0.098	958.494
A4	0.434	0.030	3506.516
P1	0.125	0.009	10033.832
P2	0.085	0.005	15951.280
P3	0.058	0.002	27345.224
P4	0.035	0.001	59520.000
P5	0.485	0.089	1307.703
P6	0.36	0.049	1756.539
P7	0.254	0.026	2794.966
P8	0.152	0.011	6190.375
P9	0.65	0.159	967.768
P10	0.561	0.107	956.876
P11	0.417	0.062	1378.136
P12	0.265	0.029	2720.323
P13	1.016	0.338	498.875
P14	0.78	0.194	623.910
P15	0.603	0.118	827.966
PC1	0.294	0.029	4836.432
PC2	0.225	0.017	6084.238
PC3	0.185	0.011	7189.816
PC4	0.162	0.008	7431.779
PC5	1.26	0.323	519.148
PC6	0.973	0.187	643.222

PC7	0.665	0.096	1092.390
PC8	0.414	0.044	2239.433
PC9	2.21	0.828	223.943
PC10	1.81	0.519	246.245
PC11	1.26	0.274	403.782
PC12	0.803	0.129	792.510
PC13	3.36	1.693	122.090
PC14	2.83	1.100	126.783
PC15	2.25	0.694	159.077

Test Fluid 6: CMC 1 % Solution; n= 0.671; k= 0.257 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	0.24	0.042	2690.679
P2	0.18	0.023	3479.290
P3	0.14	0.013	5047.426
P4	0.09	0.007	8251.698
P5	1.25	0.586	195.936
P6	0.85	0.285	315.083
P7	0.57	0.143	558.917
P8	0.33	0.060	1299.269
P9	1.10	0.597	336.694
P10	0.91	0.377	364.181
P11	0.76	0.253	419.296
P12	0.68	0.189	413.137

P13	2.30	1.854	97.405
P14	2.21	1.432	77.719
P15	1.50	0.732	133.803
PC1	0.73	0.181	784.466
PC2	0.45	0.079	1495.703
PC3	0.27	0.034	3350.601
PC4	0.20	0.019	4974.992
PC5	3.01	1.878	90.910
PC6	2.56	1.235	92.919
PC7	1.56	0.548	197.700
PC8	0.98	0.252	400.517
PC9	3.56	2.836	86.302
PC10	2.81	1.692	101.877
PC11	1.92	0.872	173.894
PC12	1.13	0.372	398.085
PC13	7.16	8.382	26.886
PC14	6.00	5.398	28.205
PC15	4.80	3.435	34.953

Test Fluid 7: CMC 0.8 % Solution; n= 0.66; k= 0.135 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	0.8	0.391	244.183
P2	0.53	0.186	405.676
P3	0.44	0.122	483.910

P4	0.26	0.051	1112.549
P5	3.37	4.206	27.130
P6	2.4	2.186	39.522
P7	1.81	1.287	54.859
P8	1.12	0.582	113.558
P9	5.5	9.774	13.517
P10	3.9	5.044	19.828
P11	2.26	2.086	46.919
P12	1.4	0.946	97.467
P13	4.02	7.480	31.885
P14	3.05	4.223	40.805
P15	2.18	2.311	63.348
PC1	2.04	1.371	100.452
PC2	1.43	0.697	150.760
PC3	1.02	0.380	238.382
PC4	0.32	0.070	1892.835
PC5	5.01	7.156	32.837
PC6	4.14	4.538	35.529
PC7	3.4	2.989	41.726
PC8	2.3	1.520	72.417
PC9	8.2	16.691	16.267
PC10	6.62	10.249	18.408
PC11	5.63	7.088	20.224
PC12	4.18	4.095	29.247

PC13	8.16	19.316	20.700
PC14	7.01	12.890	20.640
PC15	5.1	7.217	30.962

Test Fluid 8: Methocel 1.2% Solution; n= 0.718; k =1.113 Pa.s^n; ρ_f =1000kg/m^3

Particle ID	$V_t \times 10^2$	Re	C_D
A1	1.4	0.062	722.264
A2	0.93	0.029	1214.871
A3	0.60	0.014	2299.327
A4	0.42	0.008	3780.095
P1	0.15	0.005	6945.659
P2	0.10	0.003	10655.325
P3	0.08	0.002	14373.333
P5	0.36	0.027	2377.407
P6	0.26	0.014	3500.922
P7	0.21	0.009	4290.779
P9	0.64	0.070	998.247
P10	0.54	0.045	1034.220
P13	1.01	0.148	505.118
P14	0.77	0.084	640.220
P15	0.3	0.013	4644.910
PC1	0.24	0.008	5582.407
PC2	0.14	0.003	12554.667

PC3	0.11	0.002	17690.667
PC4	1.17	0.124	602.089
PC5	0.83	0.064	883.956
PC6	0.61	0.037	1296.307
PC7	0.37	0.016	2798.309
PC8	2	0.301	273.440
PC9	1.72	0.200	271.425
PC10	1	0.084	641.044
PC11	0.68	0.044	1105.142
PC12	3.15	0.637	138.912
PC13	2.37	0.355	180.775
PC14	1.61	0.183	310.684
PC15	0.38	0.024	4406.928

Test Fluid 9: Methocel 1.0% Solution; n= 0.71; k =0.893 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	1.48	0.129	646.292
A2	1.22	0.081	701.407
A3	0.73	0.036	1550.907
A4	0.47	0.017	3015.530
PC1	0.35	0.044	3393.169
PC2	0.24	0.020	5535.198
PC3	0.18	0.011	7594.798

PC5	1.53	0.218	352.087
PC6	1.21	0.130	415.926
PC7	2.73	0.562	146.756
PC8	1.82	0.268	243.546
PC13	4.02	1.564	85.292
PC14	3.1	0.899	105.660
PC15	2.29	0.517	153.568

Test Fluid 10: Methocel 0.85% Solution; n= 0.688; k =0.743 Pa.s^n; ρ_f =1000kg/m^3

Particle ID	$V_t \times 10^2$	Re	C_D
A1	2.7	0.348	194.189
A2	1.9	0.178	289.189
A3	1.41	0.103	417.950
A4	0.71	0.036	1295.564
P1	0.21	0.012	3612.179
P2	0.16	0.007	4797.003
P3	0.13	0.005	5279.461
P4	0.07	0.002	14463.797
P5	1.32	0.218	175.765
P6	0.6	0.063	632.354
P7	0.21	0.013	4088.889
P8	0.16	0.008	5524.890
P9	1.6	0.339	159.720
P10	1.2	0.189	209.430

P11	0.8	0.095	374.442
P12	0.52	0.046	701.086
P13	1.5	0.366	229.009
P14	1.13	0.204	297.272
P15	0.52	0.062	1130.701
PC1	0.56	0.044	1333.042
PC2	0.37	0.021	2251.924
PC3	0.26	0.011	3640.110
PC4	0.17	0.006	6670.073
PC5	1.62	0.284	314.053
PC6	1.22	0.159	409.135
PC7	0.73	0.069	905.153
PC8	0.64	0.050	935.275
PC9	3.5	0.947	89.287
PC10	2.39	0.466	141.231
PC11	1.94	0.302	170.327
PC12	1.3	0.153	302.377
PC13	3.1	0.947	143.429
PC14	3.05	0.751	109.153
PC15	2.14	0.402	175.850

Test Fluid 12: Sodium CMC 1.2% Solution; n=0.78; k= 1.172 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	0.103	0.0036	14730.638
P2	0.092	0.0025	13616.257
P3	0.058	0.0012	27345.224
P4	0.026	0.0004	107857.988
P5	0.42	0.0337	1746.667
P6	0.321	0.0192	2209.290
P7	0.15	0.0063	8014.222
P8	0.082	0.0025	21298.433
P9	0.76	0.0866	707.898
P10	0.41	0.0322	1794.043
P11	0.312	0.0193	2461.812
P12	0.28	0.0141	2436.667
P13	1.12	0.1663	410.771
P14	0.64	0.0662	926.725
P15	0.51	0.0419	1157.463
PC1	0.302	0.0152	5452.481
PC2	0.228	0.0085	7105.779
PC3	0.14	0.0042	16371.000
PC4	0.112	0.0025	18697.135
PC5	1.96	0.2204	214.546

PC6	1.2	0.0957	422.887
PC7	0.82	0.0501	717.365
PC8	0.51	0.0235	1472.851
PC9	1.42	0.1855	542.432
PC10	1.15	0.1131	609.998
PC11	0.95	0.0749	710.298
PC12	0.61	0.0366	1373.334
PC13	2.7	0.4865	189.074
PC14	1.54	0.1933	428.147
PC15	1.27	0.1275	499.302

Test Fluid 13: Sodium CMC 1.0% Solution; n=0.796; k= 0.381 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	0.29	0.039	1858.232
P2	0.19	0.019	3192.465
P3	0.15	0.012	4088.415
P4	0.08	0.005	11392.500
P5	1.15	0.354	232.977
P6	0.7	0.153	464.587
P7	0.53	0.090	654.222
P8	0.35	0.046	1169.067
P9	1.9	0.811	113.264
P10	1.32	0.411	173.082

P11	0.94	0.227	271.212
P12	0.6	0.110	530.652
P13	3	1.690	57.252
P14	2	0.813	94.897
P15	1.4	0.440	153.600
PC1	0.65	0.104	989.448
PC2	0.42	0.048	1747.667
PC3	0.31	0.028	2560.577
PC4	0.22	0.015	4219.353
PC5	2.55	0.923	126.751
PC6	1.9	0.509	168.686
PC7	1.1	0.219	398.641
PC8	0.75	0.115	681.046
PC9	4.23	2.126	61.128
PC10	2.8	1.015	102.898
PC11	2	0.564	160.261
PC12	1.2	0.254	354.873
PC13	7.72	5.272	23.127
PC14	5.1	2.509	39.039
PC15	3.5	1.326	65.741

Test Fluid 14: Sodium CMC 0.85% Solution; n=0.826; k= 0.132 Pa.s^n; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	0.624	0.284	401.353

P2	0.38	0.123	798.116
P3	0.28	0.072	1173.333
P4	0.09	0.016	9001.481
P5	2	1.620	61.413
P6	1.52	1.102	98.532
P7	1.1	0.710	174.942
P8	0.71	0.416	409.548
P9	3.2	4.285	39.930
P10	2.42	2.400	51.496
P11	2	1.587	59.911
P12	1.26	0.762	121.290
P13	4.85	8.450	21.905
P14	3.64	4.687	28.649
P15	3	3.084	33.451
PC1	1.4	0.733	213.287
PC2	0.95	0.362	341.594
PC3	0.65	0.192	582.418
PC4	0.41	0.093	1146.794
PC5	4.8	4.526	28.521
PC6	3.55	2.983	48.320
PC7	2.8	2.126	72.225
PC8	1.7	1.159	191.094
PC9	6.18	9.276	28.638
PC10	5.55	6.357	26.190

PC11	4.14	3.727	37.401
PC12	2.74	1.904	68.067
PC13	9.75	19.174	14.499
PC14	7.41	10.793	18.493
PC15	5.36	6.094	28.031

II E: Cylinders Settling In Vertical Orientation In Non-Newtonian Media

Units : Velocity, m/s

Test Fluid1: CMC 2.5% Solution; n=.465; k=8.07 $Pa.s^n$; $\rho_f = 1156 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	0.089	0.000273	141289.5
A2	0.038	6.39E-05	571557.6
A3	0.019	1.98E-05	1824837
A4	0.01	6.63E-06	5221471
A5	0.48	0.004989	9576.79
A6	0.1601	0.000801	63602.47
A7	0.082	0.000257	192048.1
A8	0.01525	1.73E-05	4409908
A9	1.185	0.02284	2085.236
A10	0.504	0.00532	8502.24
A11	0.24	0.00153	29794.46
A12	0.123	0.00049	90426.51
A13	2.8	0.09546	470.6666

A14	0.912	0.01475	3268.249
A15	0.693	0.00869	4489.259
S1	1.89	0.03009	71.71727
S2	0.89	0.00820	238.509
S3	0.39	0.00208	991.4245
S4	0.15	0.00043	5312.12
PC5	0.0667	0.00024	113529.4
PC6	0.074	0.00024	68147.63
PC7	0.0441	9.88E-05	151991.1
PC8	0.01862	2.36E-05	677122.7
PC9	0.621	0.008448	1738.066
PC10	0.21	0.001384	11210.2
PC11	0.085	0.000309	54372.3
PC12	0.021	3.24E-05	710108.9
PC13	0.088	0.000464	109074.1
PC14	0.0804	0.000351	96260.97
PC15	0.074	0.000278	90122.91

Test Fluid 2: CMC 1.5% Solution; n=0.546; k=1.218 $Pa.s^n$; $\rho_f = 1100 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	1.4	0.1115	620.362
A2	0.54	0.0236	3075.041
A3	0.24	0.0064	12425.674
A4	0.091	0.0014	68504.831

A5	8.349	2.1667	34.391
A6	4.12	0.6577	104.345
A7	2.15	0.2250	303.509
A8	0.858	0.0522	1513.581
P9	0.575	0.0517	1236.695
P10	0.435	0.0292	1593.757
P11	0.32	0.0165	2340.260
P13	0.908	0.1140	624.977
P14	0.695	0.0654	785.853
P15	0.497	0.0354	1218.806
PC1	0.261	0.0097	4536.089
PC2	0.154	0.0038	9608.565
PC3	0.12	0.0023	12631.111
PC4	0.0243	0.0002	244147.926
PC5	1.51	0.1803	267.191
PC6	0.601	0.0400	1246.179
PC7	0.381	0.0182	2456.182
PC8	0.0562	0.0010	89653.926
PC9	2.82	0.5219	101.664
PC10	1.3	0.1434	352.842
PC11	0.31	0.0157	4930.686
PC12	0.17	0.0058	13070.160
PC13	3.2	0.7116	99.495
PC14	1.8	0.2609	231.650

PC15	1.123	0.1158	472.0134

Test Fluid 3: CMC 1.35% Solution; n= 0.634; k= 0.628 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	4.81	1.1006	72.786
A2	1.624	0.2068	474.288
A3	0.78	0.0694	1785.972
A4	0.385	0.0217	5358.240
P1	0.3123	0.0262	1906.076
P2	0.099	0.0045	14089.229
P3	0.055	0.0019	39653.554
P4	0.026	0.0005	129700.197
P5	0.93	0.1605	356.240
P6	0.354	0.0354	1816.587
P7	0.232	0.0172	3350.178
P8	0.096	0.0044	15539.352
P9	1.13	0.2506	320.215
P10	0.673	0.1018	665.841
P11	0.405	0.0440	1461.013
P12	0.12	0.0072	13266.296
P13	2.83	1.0173	64.337
P14	1.075	0.2234	328.469
P15	0.65	0.0970	712.559
PC1	0.928	0.1041	485.427

PC2	0.471	0.0340	1389.682
PC3	0.303	0.0161	2680.254
PC4	0.058	0.0015	57978.478
PC5	3.616	1.0265	63.034
PC6	1.03	0.1524	574.000
PC7	0.55	0.0558	1594.565
PC8	0.33	0.0240	3517.801
PC9	3.5	1.1746	89.287
PC10	1.9	0.4204	223.469
PC11	1.012	0.1537	625.932
PC12	0.5715	0.0610	1564.601
PC13	6.8	3.3701	29.809
PC14	3.43	1.0901	86.307
PC15	1.81	0.3930	245.818

Test Fluid 4:CMC 1.25% Solution; n= 0.654; k= 0.472 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	5.19	1.394	52.475
A2	1.83	0.281	311.736
A3	1.03	0.112	785.451
A4	0.43	0.030	3522.731
P1	0.19	0.017	4195.477
P2	0.10	0.006	11640.918

P3	0.06	0.003	23103.552
P4	0.03	0.001	92339.256
P5	0.64	0.131	745.224
P6	0.49	0.075	940.443
P7	0.27	0.029	2401.833
P8	0.11	0.008	11315.411
P9	1.23	0.376	270.264
P10	0.87	0.194	396.614
P11	0.48	0.075	1040.116
P12	0.22	0.023	3946.997
P13	3.62	1.871	39.320
P14	1.22	0.354	255.030
P15	1.04	0.246	278.343
PC1	1.87	0.352	119.546
PC2	1.27	0.172	190.239
PC3	0.81	0.081	371.375
PC4	0.08	0.003	28311.743
PC5	2.95	1.015	94.644
PC6	1.76	0.415	196.590
PC7	0.71	0.105	952.300
PC8	0.32	0.031	3690.185
PC9	6.38	3.450	26.862
PC10	2.34	0.733	147.205
PC11	1.33	0.296	360.768

PC12	0.70	0.106	1057.953
PC13	7.93	5.377	21.919
PC14	4.38	1.980	52.928
PC15	2.09	0.629	184.365

Test Fluid 5: CMC 1.27% Solution; n= 0.785; k= 0.221 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A5	18.28	17.627	8.352
A6	5.3	3.085	73.412
A7	2.3	0.931	308.777
A8	1.12	0.324	1034.179
A9	27.5	36.167	4.898
A10	10.3	8.629	25.750
A11	4.311	2.498	116.806
A13	35.3	58.753	3.746
A14	13.4	14.234	19.150
A15	5.4	3.930	93.522
A18	87.8	266.957	1.015
A19	36.2	75.823	4.741
S5	51.3	61.814	4.000
S6	27.12	22.454	10.574
S7	12.2	7.079	41.388
S9	98.4	136.470	1.087
S10	40.3	36.345	4.789

S11	17.2	10.749	20.823
S13	90	183.337	2.173

Test Fluid 7: CMC 0.8 % Solution; n= 0.671; k= 0.257 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	1.18	0.659	112.236
P2	0.47	0.158	515.123
P3	0.42	0.115	529.012
P4	0.17	0.030	2522.907
P5	4.98	7.098	12.424
P6	2.17	1.913	48.211
P7	1.01	0.588	176.417
P8	0.65	0.280	338.960
P9	8.5	17.514	5.659
P10	4.03	5.270	18.569
P11	2	1.771	59.911
P12	0.91	0.531	230.690
P13	10.5	27.080	4.674
P14	5.82	10.027	11.226
P15	2.7	3.078	41.297
PC1	3.93	3.302	27.067
PC2	1.92	1.034	83.629
PC3	1.48	0.629	112.341

PC4	0.41	0.097	1160.259
PC5	13.31	26.501	4.652
PC6	6.08	7.594	16.479
PC7	3.01	2.539	53.240
PC8	1.22	0.650	257.383
PC9	17	44.338	3.785
PC10	8.53	14.394	11.087
PC11	6.9	9.309	13.464
PC12	2.02	1.543	125.486
PC13	19	59.950	3.818
PC14	12	26.471	7.051
PC15	6.9	10.821	16.915

Test Fluid 8: Methocel 1.2% solution; n= 0.718; k =1.1128 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	2.21	0.1717	289.846
A3	0.62	0.0230	2167.756
A4	0.23	0.0056	12062.118
P1	0.23	0.0107	3514.217
P2	0.101	0.0030	13509.999
P3	0.07	0.0017	24480.000
P4	0.035	0.0005	73662.956
P8	0.11	0.0034	12278.006
P9	0.83	0.0982	587.849
P12	0.21	0.0094	4545.739
PC1	0.36	0.0168	3200.689

Test Fluid 9: Methocel 1.0% Solution; n= 0.71; k =0.893 $\mathrm{Pa.s^n}$; $\rho_f = 1000\mathrm{kg/m^3}$

Particle ID	$V_t \times 10^2$	Re	C_D
A1	2.62	0.559	207.018
A2	1.81	0.163	318.664
A3	0.71	0.067	1657.682
A4	0.40	0.032	4066.729
PC1	0.52	0.045	1546.013
PC2	0.36	0.025	2378.769
PC3	0.17	0.006	8514.584

PC5	2.36	0.774	147.982
PC6	1.54	0.257	256.771
PC7	0.83	0.096	700.183
PC8	0.41	0.020	2335.550
PC9	3.85	1.617	73.791
PC10	2.18	0.476	169.751
PC11	1.08	0.125	549.592
PC12	0.85	0.078	707.291
PC13	6.62	3.620	31.452
PC14	4.4	1.722	52.448
PC15	2.33	0.629	148.340

Test Fluid 10: Methocel 0.85% Solution; n= 0.688; k =0.743 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
A3	1.17	0.081	608.726
A4	0.58	0.027	1963.357
P3	0.083	0.003	13353.075
P4	0.03	0.001	81013.333
P7	0.206	0.013	4249.222
P8	0.14	0.007	7306.667
P13	2.21	0.608	105.500
P14	1.23	0.228	250.900

P15	0.41	0.046	1790.934
PC1	0.67	0.056	931.258
PC2	0.41	0.024	1833.958
PC3	0.209	0.008	5633.375
PC4	0.14	0.004	9810.352
PC5	2.55	0.515	126.751
PC6	1.32	0.176	349.493
PC7	0.81	0.079	735.187
PC8	0.56	0.042	1221.583
PC9	4.6	1.356	51.690
PC10	2.64	0.531	115.749
PC11	0.96	0.120	695.577
PC12	1	0.108	511.018
PC13	5.6	2.057	43.952
PC14	3.42	0.873	86.813
PC15	1.62	0.278	308.764

Test Fluid 11: Sodium CMC 1.2% Solution; n=0.78; k= 1.172 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D
P1	0.13	0.0046	9843.621
P2	0.09	0.0022	15951.280
P3	0.054	0.0011	31429.896
P4	0.033	0.0005	69029.112

P5	0.52	0.0433	1157.202
P6	0.33	0.0198	2090.427
P7	0.15	0.0061	8576.457
P8	0.081	0.0025	21827.567
P9	0.86	0.1006	552.842
P10	0.54	0.0452	1026.602
P11	0.34	0.0215	2048.858
P13	1.4	0.2184	262.893
P14	0.8	0.0869	593.104
P15	0.42	0.0331	1706.667
PC1	0.43	0.0202	2292.789
PC2	0.24	0.0077	5582.407
PC3	0.14	0.0033	13501.864
PC4	0.11	0.0022	15274.462
PC9	2.63	0.3934	158.129
PC10	1.52`	0.1590	349.170
PC11	1.02	0.0817	616.152
PC12	0.51	0.0294	1964.697
PC14	2.22	0.3019	206.029
PC15	1.36	0.1386	435.405

Test Fluid 12: Sodium CMC 0.85% Solution; n=0.826; k= 0.132 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	$V_t \times 10^2$	Re	C_D

P1	0.91	0.442	188.718
P2	0.48	0.162	500.208
P3	0.27	0.069	1261.856
P4	0.18	0.035	2250.370
P5	3.05	3.205	33.121
P6	1.72	1.278	76.593
P7	1.03	0.573	171.631
P8	0.65	0.277	338.960
P9	5.7	8.436	12.585
P10	3	3.089	33.509
P11	1.4	1.044	122.267
P12	1	0.583	191.035
P13	6.06	10.974	14.031
P14	4.25	5.621	21.015
P15	2.08	2.007	69.586
PC1	1.52	0.808	180.939
PC2	0.95	0.362	341.594
PC3	0.65	0.192	582.418
PC4	0.41	0.093	1146.794
PC5	6.9	8.355	17.311
PC6	4	3.431	38.060
PC7	2.52	1.645	75.957
PC8	1.28	0.614	233.819
PC9	9.52	15.401	12.068

PC10	6.72	7.957	17.864
PC11	4.23	3.823	35.827
PC12	2.7	1.871	70.098
PC13	16	34.289	5.384
PC14	9.88	15.121	10.411
PC15	5.7	6.550	24.787

SETTLING VELOCITY DATA

APPENDIX III A: Cylinders Settling In Horizontal Orientation In Newtonian Media

Notations: K(exp)= $V_{t,\text{non-spherical}} / V_{t,\text{spherical}}$

K(pred): Prediction of K using Equation 4.12

K(h&c):Prediction of K using Equation 4.10 , It is Applied for the data in creeping flow region

Deviation1=deviation between K(exp) and K(pred)

Deviation2= deviation between K(exp) and K(h&c)

Test Fluid 1: Silicon Oil; μ=0.323 Pa.s; $\rho_f = 1046.8\ \text{kg/m}^3$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.625	0.400	-36.00	0.646	-3.28
P1	0.497	0.400	-19.42	0.646	-30.04
P2	0.629	0.445	-29.37	0.868	-37.98
P3	0.877	0.478	-45.55	0.941	-7.29
P5	0.461	0.399	-13.48	0.712	-54.40
P6	0.909	0.408	-55.16	0.863	5.04
P7	0.851	0.444	-47.85	0.939	-10.29
P9	0.516	0.399	-22.66	0.711	-37.86
P10	0.848	0.443	-47.80	0.864	-1.81
PC1	0.631	0.411	-34.81	0.646	-2.35
PC2	0.524	0.456	-12.96	0.868	-65.77
PC3	0.480	0.477	-0.71	-----	-----

PC4	0.406	0.508	25.13	-----	-----

Test Fluid 2: Glucose 92.5% Solution; $\mu = 10.7 \mathrm{Pa.s}$; $\rho_f = 1590 \mathrm{kg/m^3}$

Particle ID	K(exp)	K(pred)	Deviation1.	K(h&c)	Deviation2
A1	0.777	0.399	-48.66	0.646	-16.86
A2	0.833	0.443	-46.87	0.868	-4.20
A4	0.952	0.502	-47.22	0.959	-0.74
A5	0.753	0.444	-41.08	0.712	5.40
A6	0.789	0.478	-39.46	0.863	-9.38
A7	0.900	0.504	-44.02	0.939	-4.34
A8	0.782	0.336	-57.02	0.973	-24.41
A10	0.820	0.443	-45.98	0.864	-5.37
A11	0.930	0.477	-48.74	0.940	-1.03
A13	0.634	0.399	-36.98	0.713	-12.55
A14	0.815	0.444	-45.57	0.866	-6.25
S1	0.456	0.336	-26.25	-----	-----
B3	0.954	0.405	-57.58	-----	-----
B4	0.341	0.294	-13.94	-----	-----
S13	0.484	0.399	-17.42	-----	-----
S14	0.742	0.444	-40.24	-----	-----
S9	0.657	0.399	-39.27	-----	-----
S10	0.846	0.443	-47.65	-----	-----
S11	0.946	0.477	-49.60	-----	-----

Test Fluid 3 : Glucose 87.5% Solution; $\mu = 1.28$ Pa.s; $\rho_f = 1375\ \mathrm{kg/m^3}$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.396	0.400	1.14	-----	-----
A2	0.592	0.445	-24.88	0.868	-46.75
A3	0.769	0.478	-37.94	0.941	-22.28
A5	0.575	0.399	-30.58	0.712	-23.89
A6	0.827	0.443	-46.44	0.863	-4.44
A9	0.447	0.399	-10.73	-----	-----
A10	0.747	0.443	-40.76	0.864	-15.55
A11	0.758	0.477	-37.11	0.940	-23.94
A13	0.456	0.399	-12.41	-----	-----
A14	0.700	0.444	-36.64	0.866	-23.69
A15	0.893	0.478	-46.49	0.941	-5.42

Test Fluid 4 : Glucose 72% Solution; $\mu = 0.54$ Pa.s; $\rho_f = 1230\ \mathrm{kg/m^3}$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.459	0.400	-12.70	0.646	-40.88
A2	0.618	0.445	-28.06	0.868	-40.52
A3	0.589	0.478	-18.91	0.941	-59.77
A4	0.678	0.503	-25.82	0.959	-41.38
A5	0.355	0.399	12.42	-----	-----
A6	0.459	0.443	-3.59	-----	-----
A7	0.642	0.477	-25.72	0.939	-46.24

PC9	0.335	0.399	19.20	-----	-----
PC10	0.500	0.443	-11.39	-----	-----
PC11	0.586	0.477	-18.69	0.940	-60.25
PC12	0.714	0.502	-29.66	0.958	-34.13
PC13	0.340	0.399	17.57	-----	-----
PC14	0.476	0.444	-6.85	-----	-----
PC15	0.554	0.478	-13.68	-----	-----

Test Fluid 5: Glucose 50% Solution; $\mu = 0.204$ Pa.s; $\rho_f = 1050\ \mathrm{kg/m^3}$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.434	0.400	-7.72	0.646	-48.92
A2	0.654	0.445	-32.03	0.868	-32.78
A3	0.641	0.478	-25.50	0.941	-46.79
A4	0.624	0.503	-19.42	-----	-----
PC9	0.320	0.399	24.48	-----	-----
PC10	0.506	0.443	-12.48	-----	-----
PC11	0.617	0.477	-22.73	-----	-----
PC14	0.378	0.444	17.24	-----	-----
PC15	0.414	0.478	15.35	-----	-----
A9	0.318	0.443	39.08	-----	-----
A10	0.406	0.477	17.51	-----	-----
A14	0.278	0.444	59.88	-----	-----
A15	0.366	0.478	30.48	-----	-----
S1	0.359	0.393	9.54	-----	-----

S2	0.537	0.435	-18.96	-----	-----
S3	0.602	0.457	-24.10	-----	-----

III B. Cylinders Settling In Vertical Orientation In Newtonian Media

Notations: K(pred): Prediction of K using Equation 4.12

K(h&c):Prediction of K using Equation 4.11 , It is Applied for the data in creeping flow region

Test Fluid 1 : Glucose 87.5% Solution; μ = 1.28 Pa.s; $\rho_f = 1375\ \mathrm{kg/m^3}$.

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.613	0.714	-16.40	0.646	-5.34
A2	0.848	0.593	30.09	0.868	-2.44
A3	0.904	0.513	43.20	0.941	-4.11
A5	0.719	0.716	0.49	0.959	-33.28
A9	0.591	0.717	-21.38	0.711	-20.35
A10	0.848	0.596	29.69	0.864	-1.86
A13	0.662	0.715	-7.98	0.713	-7.68
A14	0.836	0.594	28.93	0.866	-3.62
A15	0.858	0.513	40.24	0.941	-9.74

Test Fluid 2 : Glucose 75% Solution; $\mu = 0.54$ Pa.s; $\rho_f = 1230\ \text{kg/m}^3$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.809	0.714	11.76	0.646	20.14
PC9	0.745	0.717	3.77	0.711	4.59
PC10	0.806	0.596	26.03	0.864	-7.17
PC11	0.673	0.515	23.46	0.940	-39.67
PC13	0.675	0.715	-5.97	0.713	-5.68
PC14	0.694	0.594	14.35	0.866	-24.88
PC15	0.617	0.513	16.99	0.941	-52.45
G1	0.633	0.703	-11.15	0.857	-35.41
G2	0.569	0.680	-19.62	0.853	-49.91
G3	0.557	0.657	-17.83	0.858	-53.95
G4	0.504	0.632	-25.47	0.833	-65.30
G5	0.488	0.612	-25.61	0.820	-68.08
G6	0.514	0.577	-12.20	0.821	-59.87
G8	0.498	0.480	3.69	0.718	-44.07
G9	0.581	0.679	-16.84	0.861	-48.15
G10	0.618	0.650	-5.19	0.888	-43.73
G11	0.579	0.623	-7.59	0.874	-50.91
G12	0.644	0.579	10.12	0.902	-39.94
G13	0.563	0.562	0.11	0.846	-50.16

Test Fluid 3 : Glucose 72% Solution; $\mu = 0.4$ Pa.s; $\rho_f = 1100\ kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.637	0.714	-11.99	0.646	-1.35
A2	0.653	0.593	9.29	0.868	-32.93
A3	0.630	0.513	18.58	0.941	-49.23
A5	0.444	0.716	-61.23	0.712	-60.45
A6	0.698	0.595	14.71	0.863	-23.70
A7	0.676	0.513	24.13	0.939	-38.83
PC9	0.524	0.717	-36.77	-----	-----
PC10	0.643	0.596	7.30	-----	-----
PC11	0.615	0.515	16.20	-----	-----
PC12	0.670	0.446	33.47	-----	-----
PC13	0.456	0.715	-56.81	-----	-----
PC14	0.564	0.594	-5.26	-----	-----
PC15	0.596	0.513	13.93	-----	-----

Test Fluid 4 : Glucose 80% Solution; $\mu = 0.652$ Pa.s; $\rho_f = 1270\ kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.936	0.714	23.76	-----	-----
A5	0.576	0.716	-24.38	0.712	-23.78
A6	0.599	0.595	0.59	0.863	-44.19
A7	0.630	0.513	18.54	0.939	-49.06
A9	0.470	0.717	-52.71	0.711	-51.41

Test Fluid 5: Glucose 50% Solution; $\mu = 0.204$ Pa.s; $\rho_f = 1050\ \mathrm{kg/m^3}$

Particle ID	K(exp)	K(pred)	Deviation1	K(h&c)	Deviation2
A1	0.596	0.714	-19.82	0.646	-8.44
A2	0.713	0.593	16.83	0.868	-21.88
A3	0.837	0.513	38.70	0.941	-12.35
A4	0.611	0.443	27.51	0.959	-56.91
PC9	0.409	0.717	-75.30	0.711	-73.80
PC10	0.936	0.596	36.33	0.864	7.76
PC12	0.846	0.446	47.30	0.940	-11.10
PC14	0.403	0.594	-47.29	-----	-----
PC15	0.360	0.513	-42.43	-----	-----
G1	0.457	0.703	-53.97	-----	-----
G2	0.461	0.680	-47.62	-----	-----
G3	0.477	0.657	-37.65	-----	-----
G4	0.523	0.632	-20.78	0.833	-59.12
G5	0.558	0.613	-9.72	0.820	-46.78
G6	0.605	0.577	4.69	0.821	-35.81
G7	0.693	0.531	23.44	0.719	-3.78
G8	0.690	0.480	30.44	0.718	-4.06
A10	0.410	0.596	-45.39	-----	-----
A11	0.414	0.515	-24.43	-----	-----

III C: Cylinders Settling In Horizontal Orientation In Non-Newtonian Media

Notations: $K(exp) = {}^{V_{t,non\text{-}spherical}}\!/\!_{V_{t,spherical}}$

K(pred): Prediction of K using Equation 4.18

Test Fluid 1: CMC 1.5% Solution; n=0.546; k=1.218 $Pa.s^n$; $\rho_f = 1100 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation
A5	0.389	0.310	20.33
A6	0.493	0.357	27.58
A7	0.548	0.391	28.62
A8	0.483	0.434	10.19
A1	0.244	0.311	-27.16
A2	0.289	0.358	-24.07
A3	0.393	0.392	0.30
A4	0.366	0.417	-14.10
P9	0.200	0.309	-54.42
P10	0.254	0.357	-40.54
P11	0.282	0.391	-38.67
P12	0.276	0.417	-50.86
P14	0.239	0.358	-49.61
P15	0.282	0.392	-38.92
P16	0.274	0.418	-52.63

A6	0.493	0.357	27.58
A7	0.548	0.391	28.62
A8	0.483	0.434	10.19
A1	0.244	0.311	-27.16
A2	0.289	0.358	-24.07
A3	0.393	0.392	0.30
A4	0.366	0.417	-14.10
P9	0.200	0.309	-54.42
P10	0.254	0.357	-40.54
P11	0.282	0.391	-38.67
P12	0.276	0.417	-50.86
P14	0.239	0.358	-49.61
P15	0.282	0.392	-38.92
P16	0.274	0.418	-52.63
PC1	0.193	0.311	-61.26
PC2	0.220	0.358	-63.16
PC3	0.263	0.392	-49.09
PC6	0.241	0.346	-43.57
PC7	0.249	0.371	-48.76
PC8	0.293	0.402	-37.40
PC9	0.197	0.309	-56.83
PC10	0.284	0.357	-25.75
PC11	0.328	0.391	-19.48
PC12	0.310	0.417	-34.48
PC13	0.234	0.310	-32.35
PC14	0.339	0.358	-5.37
PC15	0.387	0.392	-1.32

Test Fluid 2: CMC 1.35% Solution; n= 0.634; k= 0.628 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation

A1	0.234	0.261	-11.55
A2	0.308	0.321	-4.36
A3	0.311	0.358	-15.10
A4	0.311	0.366	-17.57
A5	0.158	0.261	-65.70
A6	0.190	0.321	-68.95
P1	0.153	0.260	-70.04
P2	0.188	0.319	-69.53
P3	0.206	0.358	-73.63
P5	0.171	0.259	-51.57
P6	0.208	0.319	-53.49
P7	0.235	0.358	-52.13
P8	0.216	0.366	-69.58
P9	0.150	0.260	-73.58
P10	0.226	0.320	-41.79
P11	0.265	0.359	-35.53
P14	0.204	0.358	-75.81
PC6	0.208	0.319	-53.32
PC7	0.226	0.358	-58.51
PC10	0.228	0.319	-39.97
PC11	0.253	0.358	-41.67
PC12	0.248	0.366	-47.30
PC13	0.163	0.260	-59.24
PC14	0.233	0.320	-37.26
PC15	0.311	0.359	-15.21

Test Fluid 3: CMC 1 % Solution; n= 0.671; k= 0.257 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation
P1	0.162	0.261	-61.46

P2	0.222	0.321	-44.76
P3	0.259	0.358	-38.30
P4	0.287	0.366	-27.39
P5	0.232	0.260	-12.08
P6	0.273	0.319	-16.93
P7	0.287	0.358	-24.72
P8	0.263	0.379	-44.14
P12	0.308	0.366	-18.96
P13	0.188	0.260	-38.41
P14	0.287	0.320	-11.71
P15	0.289	0.359	-24.06
PC1	0.187	0.261	-39.88
PC2	0.210	0.321	-53.07
PC4	0.226	0.366	-62.20
PC5	0.233	0.260	-11.56
PC6	0.326	0.319	2.03
PC7	0.305	0.358	-17.28
PC8	0.295	0.379	-28.63
PC9	0.238	0.259	-8.76
PC10	0.225	0.319	-42.08
PC11	0.225	0.358	-59.32
PC13	0.279	0.260	6.64
PC14	0.341	0.320	6.07
PC15	0.384	0.359	6.53

Test Fluid 4: CMC 0.8 % Solution; n= 0.66; k= 0.153 Pa.s^n; ρ_f =1000kg/m^3

Particle ID	K(exp)	K(pred)	Deviation
P1	0.287	0.311	-8.40
P2	0.346	0.358	-3.58
P3	0.445	0.392	11.87

P4	0.413	0.417	-1.05
P5	0.387	0.305	21.25
P6	0.449	0.346	22.92
P7	0.504	0.371	26.41
P8	0.482	0.402	16.50
P9	0.428	0.309	27.80
P10	0.459	0.357	22.26
P11	0.383	0.391	-2.19
P12	0.351	0.417	-18.73
P13	0.241	0.310	-28.82
P14	0.262	0.358	-36.71
P15	0.256	0.392	-53.00
PC1	0.294	0.311	-5.75
PC2	0.358	0.358	-0.28
PC3	0.391	0.392	-0.34
PC5	0.266	0.305	-14.72
PC6	0.329	0.346	-4.99
PC7	0.382	0.371	3.10
PC8	0.389	0.402	-3.58
PC9	0.319	0.309	3.07
PC10	0.363	0.357	1.73
PC11	0.415	0.391	5.58
PC12	0.433	0.417	3.72
PC13	0.258	0.310	-20.16
PC14	0.296	0.358	-20.84
PC15	0.279	0.392	-40.81

Test Fluid 5: Sodium CMC 1.0% Solution; n=0.796; k= 0.381 $Pa.s^n$;

$$\rho_f = 1000 kg/m^3$$

Particle ID	K(exp)	K(pred)	Deviation
P1	0.284	0.311	-9.46

P2	0.342	0.358	-4.79
P3	0.424	0.392	7.51
P4	0.360	0.417	-15.93
P5	0.290	0.305	-5.30
P6	0.323	0.346	-7.05
P7	0.386	0.371	4.02
P8	0.408	0.402	1.39
P9	0.272	0.309	-13.79
P10	0.347	0.357	-2.76
P11	0.391	0.391	0.00
P12	0.393	0.417	-5.96
P13	0.270	0.310	-14.69
P14	0.332	0.358	-7.73
P15	0.369	0.392	-6.23
PC1	0.238	0.311	-30.64
PC2	0.283	0.358	-26.81
PC3	0.328	0.392	-19.71
PC4	0.362	0.417	-15.39
PC5	0.240	0.305	-27.03
PC6	0.328	0.346	-5.50
PC7	0.302	0.371	-22.53
PC8	0.327	0.402	-23.09
PC9	0.226	0.309	-36.73
PC10	0.275	0.357	-29.59
PC11	0.311	0.391	-25.72
PC12	0.294	0.417	-41.72
PC13	0.260	0.310	-19.22
PC14	0.316	0.358	-13.01
PC15	0.345	0.392	-13.66

III D: Cylinders Settling In Vertical Orientation In Non-Newtonian Media

Notation: K(pred): Prediction of K using Equation 4.18

Test Fluid 1: CMC 1.5% Solution; n=0.546; k=1.218 $Pa.s^n$; $\rho_f = 1100 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation
A1	0.486	0.604	-24.21
A2	0.328	0.499	-52.01
A3	0.239	0.426	-78.05
A5	0.768	0.607	20.92
A6	0.680	0.503	26.00
A7	0.561	0.427	23.97
A8	0.355	0.358	-0.86
P10	0.367	0.504	-37.35
P11	0.426	0.429	-0.62
PC3	0.415	0.427	-2.86
PC5	0.460	0.607	-32.10
PC6	0.333	0.503	-51.18
PC7	0.335	0.427	-27.25
PC9	0.492	0.608	-23.64
PC10	0.412	0.504	-22.42

Test Fluid 2: CMC 1.35% Solution; n= 0.634; k= 0.628 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation
A1	0.873	0.454	47.97
A2	0.493	0.400	18.88
A3	0.402	0.330	17.85
A4	0.316	0.492	-55.82
A5	0.505	0.454	10.12
A6	0.270	0.400	-47.87
A7	0.256	0.330	-29.11

P1	0.389	0.455	-17.00
P2	0.271	0.400	-47.73
P3	0.281	0.330	-17.50
P5	0.275	0.456	-65.55
P6	0.295	0.401	-36.30
P7	0.279	0.333	-19.12
P9	0.448	0.455	-1.59
P10	0.299	0.399	-33.75
P11	0.286	0.492	-72.11
P12	0.562	0.454	19.24
P13	0.481	0.400	16.78
P14	0.528	0.330	37.43
PC5	0.581	0.455	21.66
PC6	0.301	0.400	-33.09
PC7	0.251	0.330	-31.75
PC9	0.336	0.456	-35.74
PC10	0.318	0.401	-26.05
PC11	0.264	0.333	-26.02
PC13	0.441	0.455	-3.09
PC14	0.376	0.399	-6.31
PC15	0.305	0.328	-7.62

Test Fluid 3:CMC 1.25% Solution; n= 0.654; k= 0.472 $\mathrm{Pa.s^n}$; $\rho_f = 1000\mathrm{kg/m}$

Particle ID	K(exp)	K(pred)	Deviation
A1	0.719	0.606	15.82
A2	0.456	0.501	-9.81
A3	0.401	0.427	-6.57
A4	0.267	0.357	-33.86
P7	0.251	0.427	-69.77

P10	0.293	0.504	-72.16
P11	0.251	0.429	-70.79
P13	0.453	0.607	-34.13
P15	0.351	0.426	-21.65
PC1	0.858	0.606	29.40
PC5	0.370	0.607	-64.05
PC6	0.386	0.503	-30.34
PC7	0.246	0.427	-73.18
PC9	0.488	0.608	-24.73
PC10	0.305	0.504	-64.99
PC11	0.266	0.429	-61.31
PC12	0.214	0.360	-68.26
PC13	0.424	0.607	-43.28
PC14	0.380	0.502	-32.25
PC15	0.274	0.426	-55.46

Test Fluid 4: CMC 1 % Solution; n= 0.671; k= 0.257 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation
P1	0.379	0.492	-29.68
P2	0.283	0.454	-60.47
P3	0.349	0.400	-14.50
P5	0.347	0.492	-41.70
P6	0.318	0.455	-43.02
P7	0.283	0.400	-41.22
P9	0.386	0.492	-27.42
P10	0.342	0.456	-33.22
P11	0.306	0.401	-31.28
P13	0.408	0.492	-20.41
P14	0.529	0.455	14.08
P15	0.272	0.399	-46.98
PC1	0.471	0.492	-4.44

PC2	0.310	0.454	-46.63
PC3	0.264	0.400	-51.34
PC5	0.405	0.492	-21.38
PC6	0.425	0.455	-7.18
PC7	0.359	0.400	-11.34
PC9	0.730	0.492	32.59
PC10	0.599	0.456	23.83
PC13	0.577	0.492	14.82
PC14	0.568	0.455	19.94
PC15	0.355	0.399	-12.53

Test Fluid 5: CMC 0.8 % Solution; n= 0.66; k= 0.153 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Particle ID	K(exp)	K(pred)	Deviation
P1	0.423	0.606	-43.19
P2	0.307	0.501	-63.00
P3	0.426	0.427	-0.38
P4	0.274	0.357	-30.15
P5	0.572	0.607	-6.11
P6	0.406	0.503	-23.86
P7	0.281	0.427	-51.97
P8	0.279	0.358	-28.18
P9	0.662	0.608	8.08
P10	0.474	0.504	-6.25
P11	0.339	0.429	-26.48
P12	0.228	0.360	-57.76
P13	0.628	0.607	3.41
P14	0.499	0.502	-0.65
P15	0.318	0.426	-34.24

VISCOMETRIC DATA

APPENDIX IV: Shear Stress-Shear Rate Data For Some Of The Non-Newtonian Fluids Used In The Study

Units: Shear Stress, Pa

Shear Rate, s^{-1}

Test Fluid 1: CMC 1 % Solution; n= 0.671; k= 0.257 $Pa.s^n$;

Shear Stress	Shear Rate
1.501	13.836
4.120	62.213
7.252	144.450

Test Fluid 2: CMC 0.8 % solution; n= 0.671; k= 0.257 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Shear Stress	Shear Rate
1.075	23.195
2.965	107.840
5.092	244.780

Test Fluid 3: SCMC 1.2% Solution; n=0.78; k= 1.172 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Shear Stress	Shear Rate
2.9	3.1889
7.64	11.065
12.1	19.956

65.7	174.61
72	196.36

Test Fluid 4: SCMC 1% Solution; n=0.796; k= 0.381 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Shear Stress	Shear Rate
1.202	4.227
3.218	14.564
5.273	27.078
7.269	40.519
9.366	55.713
11.604	72.907
13.863	91.158
16.277	111.520
18.820	133.820
21.371	156.980
23.930	180.940
26.657	207.200
29.382	234.140

Test Fluid 5: Methocel 1.0% Solution; n= 0.71; k =0.893 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Shear Stress	Shear Rate
2.673	5.166
7.555	18.717
12.545	38.055
17.555	62.846
22.558	93.322
27.518	129.580
32.517	172.180

37.524	221.520

Test Fluid 6: Methocel 0.85% Solution; n= 0.688; k =0.743 $Pa.s^n$; $\rho_f = 1000 kg/m^3$

Shear Stress	Shear Rate
1.501	2.777
3.661	10.142
5.842	19.994
8.235	32.929
10.863	49.235
13.549	67.870
16.469	90.111
19.692	116.830
22.958	146.000
26.487	179.710
30.304	218.520
34.152	259.970